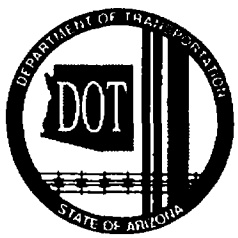


ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA-AZ88-839

NUCLEAR DENSITY TESTING OF GRANULAR MATERIALS

State of the Art

Final Report

Prepared by:
Michael S. Mamlouk
Center for Advanced Research in Transportation,
and the Department of Civil Engineering
College of Engineering & Applied Sciences
Arizona State University
Tempe, Arizona 85287-5306

November 1988

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
In cooperation with
U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Arizona Department of Transportation or the Federal Highways Administration. This report does not constitute a standard, specification, or regulation. Trade or manufacturer's names which may appear herein are cited only because they are considered essential to the objectives of the report. The U.S. Government and the State of Arizona do not endorse products or manufacturers.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-AZ88-839		

4. Title and Subtitle	5. Report Date
NUCLEAR DENSITY TESTING OF GRANULAR MATERIALS	November, 1988
	6. Performing Organization Code

7. Author (s)	8. Performing Organization Report No.
Michael S. Mamlouk	

9. Performing Organization Name and Address	10. Work Unit No.
Center for Advanced Research in Transportation Arizona State University Tempe, Arizona 85287-5306	11. Contract or Grant No. HPR-PL-1(35)Item 839

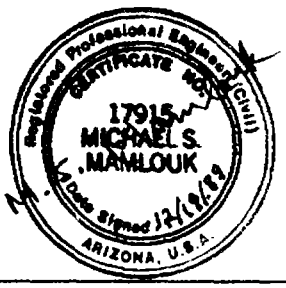
12. Sponsoring Agency Name and Address	13. Type of Report & Period Covered
ARIZONA DEPARTMENT OF TRANSPORTATION 206 SOUTH 17TH AVENUE PHOENIX, ARIZONA 85007	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Nuclear methods have been used by a number of states for many years to determine both density and moisture contents of subgrade, subbase and base materials. Although nuclear methods have been used in Arizona for spot checks, they have not been standardized for acceptance specifications by ADOT. The objective of this study was to review the literature related to the use of nuclear density testing of granular materials and make recommendations for ADOT use. The main advantage of nuclear gauges is that they are rapid and nondestructive. On the other hand, the results may not be very accurate. Most of the studies comparing nuclear densities with volumeter (rubber balloon) and sand cone densities have been performed in the 1960's and 70's. Most of these studies concluded that nuclear densities are generally not less accurate than the volumeter or the sand cone densities. Although the correlations are not excellent, there is no reason to believe that one method is more accurate than the other. Based on the telephone survey conducted in the study, most of the states which were contacted are currently using nuclear gauges for acceptance specifications or quality assurance for controlling compaction of subgrade, subbase, and base courses. Some of these state indicated that they are using conventional methods only in cases of disputes or disagreements. The use of nuclear gauges for moisture content determination, however, seems to be less frequent than their use for density determination. Based on this study it is recommended that ADOT would use nuclear density methods for acceptance specifications. A research study could be performed on typical Arizona materials to compare densities obtained by nuclear methods and the volumeter method currently used.

17. Key Words	18. Distribution Statement	23. Registrant's Seal
Nuclear Density Testing, Nuclear Methods, Nuclear Gauges, Granular Materials	Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia, 22161	

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	62	

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

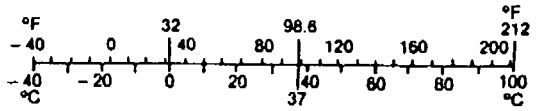
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
AREA				
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. PROBLEM STATEMENT

For determining the density of the compacted subgrade soils and aggregate base and sub-base materials, Arizona has basically relied on the rubber balloon (velumeter) test. The test is very time consuming and is becoming obsolete. As innovations in construction methods and equipment continue to increase the rate of highway construction, it becomes increasingly important to improve on rapid methods for control testing. The most significant breakthrough in this field in recent years has been the use of nuclear methods. They are not only far more rapid than conventional methods, but they offer as well a greater degree of freedom from human error and require less judgment on the part of the operator.

Although nuclear gauges first became available in the late 1950's, growth in their acceptance and use has been rather slow until the late 1960's due largely to questions concerning measurement accuracy. Until now, the precision and accuracy of the nuclear methods have not been fully determined. Compounding the problem is the fact that both nuclear and conventional (volumeter and sand cone) methods do not provide absolute values of in-place density. Also, the variability of soil as well as the destructive nature of conventional methods do not permit duplication of test results for obtaining meaningful statistical evaluation.

Nuclear methods have been used by a number of states for many years to determine both density and moisture contents. Although nuclear methods have been used in Arizona for spot checks, they have not been standardized for acceptance specifications by ADOT.

There is a great need to determine the reliability of the data obtained from nuclear methods and their correlation with those obtained from other methods particularly the volumeter test which has been part of the Arizona testing program for a considerable length of time.

2. RESEARCH OBJECTIVE

The objective was to review the literature related to the use of nuclear density testing of granular materials. Particular attention was devoted to compare the test results obtained by nuclear, volumeter, and sand cone methods. Transportation Research Information System (TRIS) computer search was performed and technical articles were reviewed in various journals as well as publications by state, federal and private highway agencies. Other state DOT's, Army Corps of Engineer and other engineering organizations were contacted to secure their current practice. This final report was prepared and submitted to ADOT including the state-of-the-art overview, opinions, experiences and recommendations.

3. BASIC CONCEPTS AND BRIEF DESCRIPTIONS

The following sections discuss basic concepts and brief descriptions of nuclear, rubber balloon (volumeter), and sand cone methods. Since detailed test procedures are published in ASTM and AASHTO standards, these sections concentrate on assumptions, basic concepts, advantages and disadvantages, as well as other factors that might affect the comparison among various methods.

3.1 Nuclear Methods

Many nuclear instruments for measuring in-place density and moisture content of soil and granular materials are available from various manufacturers. These instruments consist of both separate and combined density and moisture content gauges. The determination of density is

standardized by ASTM D2922-81 (AASHTO T238-79) test procedure, while the moisture determination is standardized by ASTM D3017-78 (AAHTO T239-76) test procedure.

A wide variety of gauge configurations is possible, involving source energy and intensity, type and efficiency of detector, and source-detector separation. The most universally employed method of determining density is with a gamma-ray gauge by use of a calibration curve prepared from the empirically determined relationships between density and response for each individual instrument. The calibration curve for a particular instrument is originally obtained by plotting the response measured by the gauge for a set of calibration standards of known density.

The basic assumptions and procedure used for both density determination and moisture content determination are presented in the following sections.

3.1.1 Density Determination

Nuclear methods cover the determination of the total or wet density of soil and soil-aggregate in place by the attenuation of gamma rays where the gamma source or gamma detector, or both, remain at or near the surface. The methods described are normally suitable to a test depth of approximately 2 to 12 in., depending on the test geometry used. Three methods of nuclear density are available:

- Backscatter,
- Direct transmission, and
- Air gap.

The ability of a soil to absorb gamma radiation is directly proportional to the density of the soil. Gamma radiation is absorbed by three means, depending on the energy of the source: (a) photo electric effect (low

gamma energies), (b) Compton effect (medium gamma energies), and (c) ionpair production (high gamma energies).

Backscatter-type nuclear density gauges are predicated on the use of the Compton effect absorption principle of medium-energy gamma photons. A definite relation exists between the number of gamma photons that are scattered back from a material and the density of the material. The backscatter gauge measures gamma photons that have been scattered by Compton effect as illustrated in Figure 1. The gamma counts are inversely proportional to density.

The direct transmission gauge measures both gamma photons that are transmitted directly from the source without energy loss and those that have been scattered by Compton effect. Similar to the backscatter method, the gamma counts are inversely proportional to density. A schematic diagram of the direct transmission gauge is shown in Figure 2.

A special case of the backscatter nuclear density method is the air-gap backscatter method. Kuhn (32) proposed that the introduction of a deliberate air gap between the nuclear instrument and the soil might reduce calibration errors caused by chemically different soils. The air gap at which a maximum reading divided by the reading at the surface of the material occurs is then computed for different densities to establish calibration curves. A schematic diagram of the air-gap method is presented in Figure 3.

Recently nuclear gauges have been developed to be mounted on the roller during compaction of asphalt concrete so that a continuous density reading can be obtained during compaction. Using this method an immediate decision can be taken by the roller operator if further compaction is needed. The available roller mounted gauges, however, cannot be used for granular material compaction.

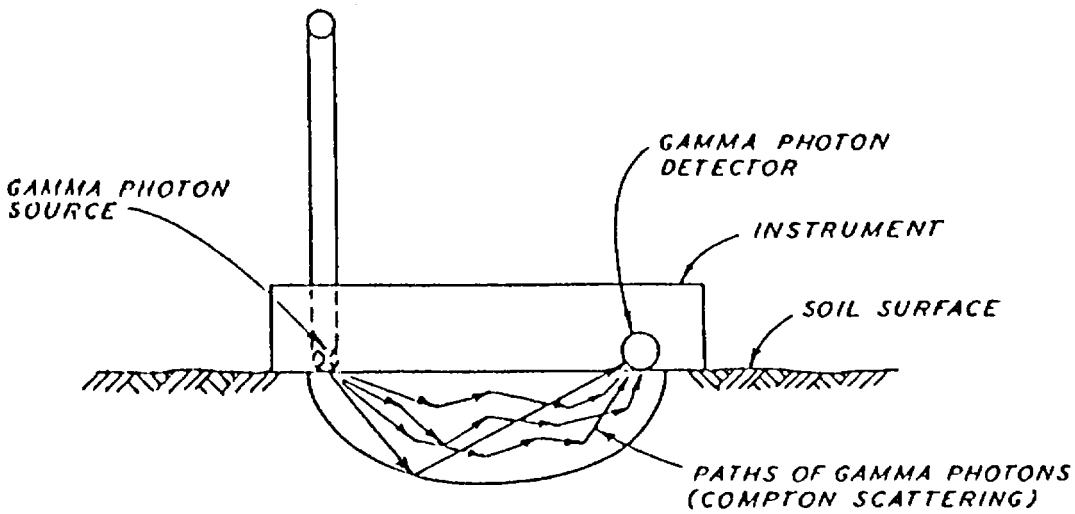


Figure 1. Backscatter density measurement.

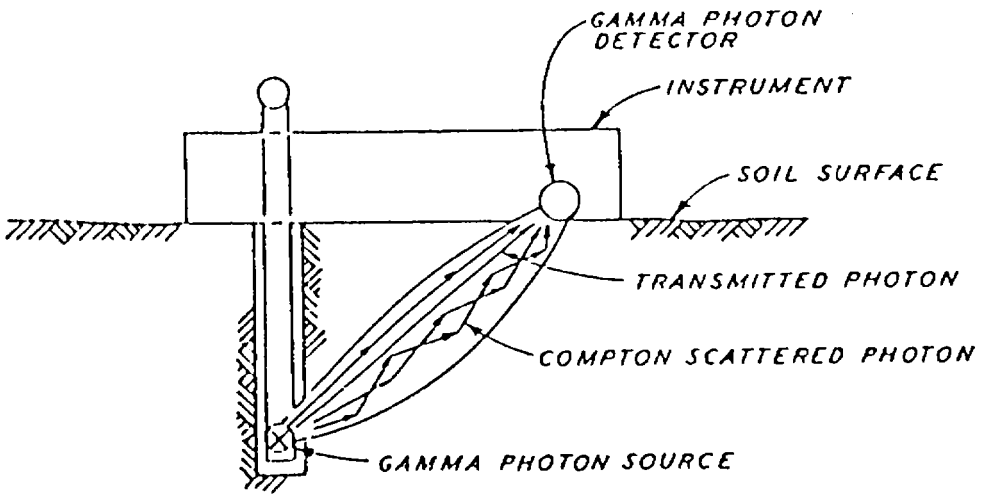


Figure 2. Direct transmission density measurement

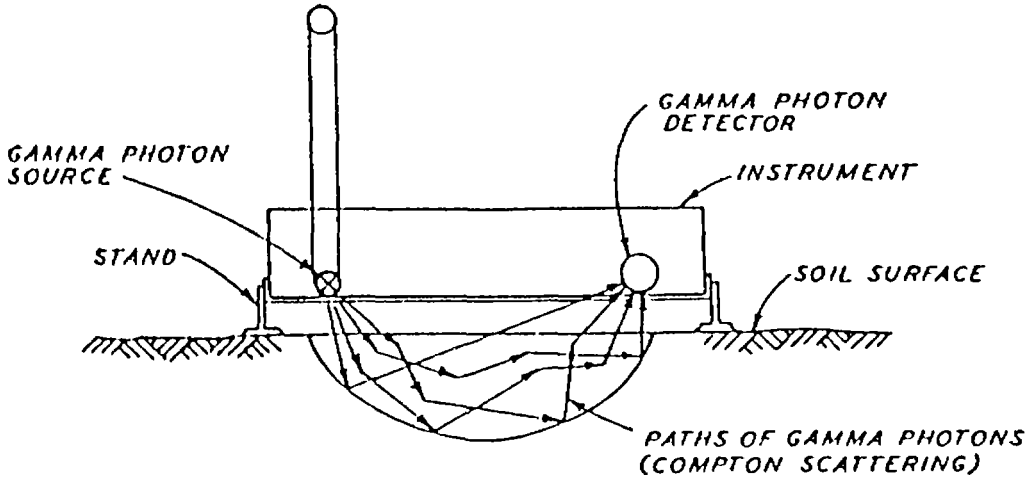


Figure 3. Air-gap density measurement

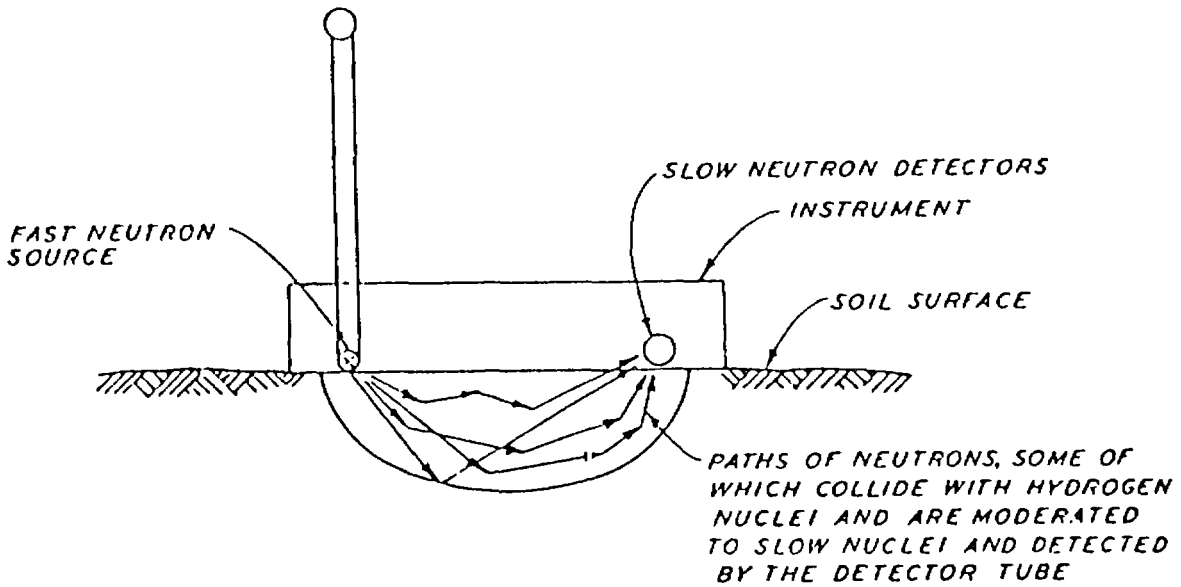


Figure 4. Backscatter moisture measurement

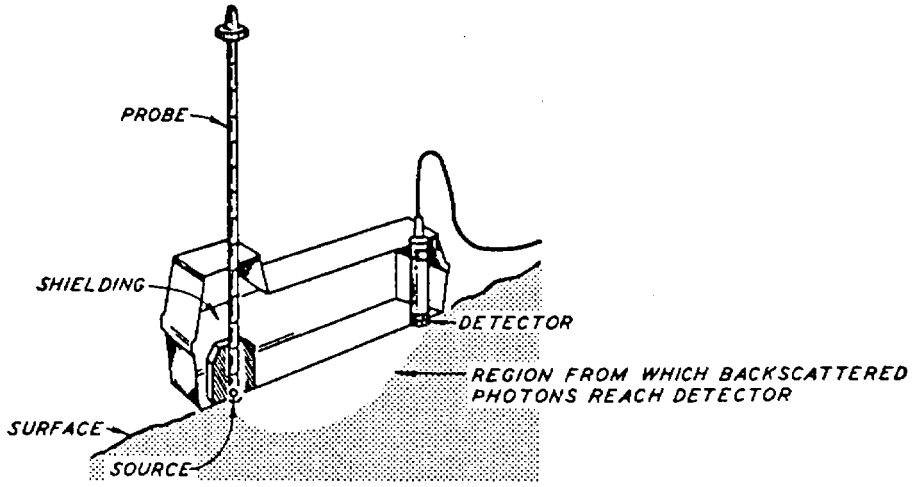
3.1.2 Moisture Content Determination

The nuclear measurement of soil water content is predicated on the principle that when a high energy neutron collides with a nucleus of an atom very much heavier than the neutron, little energy is lost by the neutron. However, when the neutron collides with a nucleus of similar mass, the neutron loses considerable energy and becomes a slow or low-energy neutron. The hydrogen nucleus, which has approximately the same mass as the neutron, is the most effective element in slowing fast neutrons. Therefore, the number of neutrons slowed down by transmission through soil is a function of the water content, since most hydrogen found in soil is in the form of soil moisture. The amount of water in a given soil mass can be determined by emitting fast neutrons into the soil and counting the number of slow neutrons that are scattered back. A schematic diagram of the backscatter moisture measurement technique is given in Figure 4.

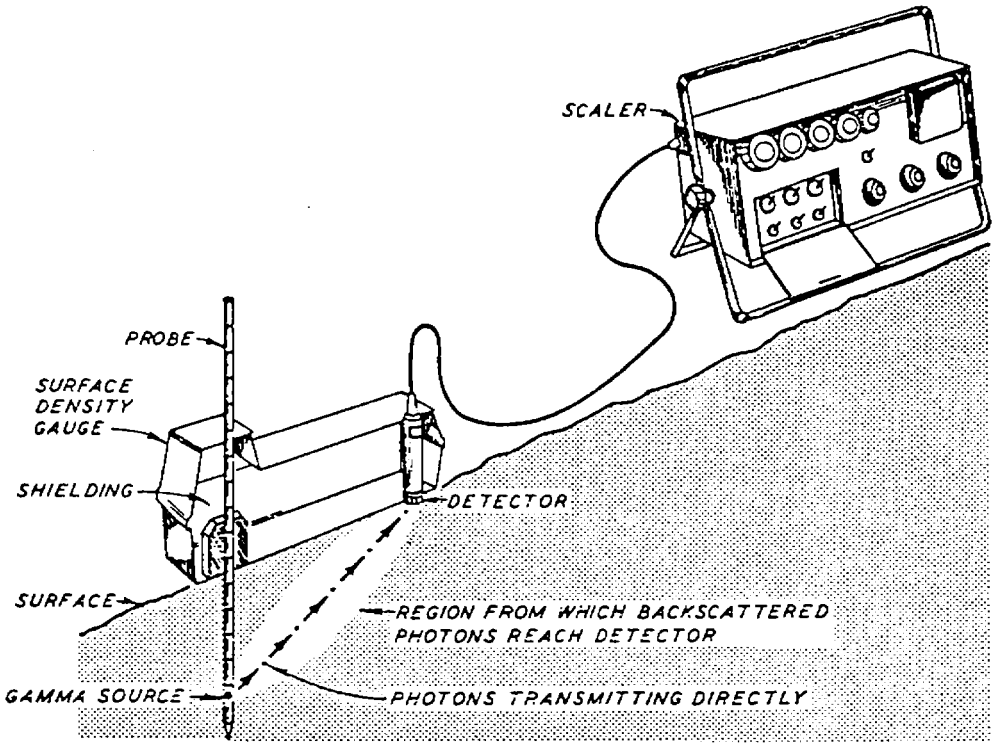
Figure 5 illustrates how a typical combined nuclear device can be used for density and moisture determination using the backscatter method and density determination using the direct transmission method.

3.1.3 Advantages and Disadvantages

The main advantage of nuclear methods is that they are rapid and nondestructive. In fact, about 10 nuclear measurements can be made in the same time normally required for the conventional density tests. Moreover, they offer greater degree of freedom from human error and require less judgement on the part of the operation (31). On the other hand, nuclear methods have several disadvantages that are inherit in the test procedure.



a. BACKSCATTER MOISTURE AND DENSITY METHOD



b. DIRECT TRANSMISSION DENSITY METHOD

Figure 5. A sketch of backscatter and direct transmission gauge (40)

For example, the determination of density using nuclear methods is indirect. As a result, calibration relations have to be developed. These calibration relations may vary with different soils depending on their chemical composition, heterogeneity and surface texture. Therefore, calibration curves developed by the manufacturers or developed for a specific type of soil might not be valid under other conditions different from those that were used in the original development. Also, the nuclear apparatus is more sensitive to certain regions of the material under test. Thus, the density or moisture content determined by the nuclear methods is not necessarily the average density or moisture content within the volume of the soil involved in the measurement. In addition, the equipment utilizes radioactive materials which may be hazardous to the health of users unless proper precautions are taken.

The research and development work carried out on the technique of determining density and moisture content are reported in many references (e.g., 8,9,12,28,35,41). Examples of different field applications are also presented.

3.2 Rubber Balloon (Volumeter) Method

Detailed procedure of the method is published in ASTM D2167-84, AASHTO T205-82 and ARIZ 231a test procedures. The method can be summarized in digging out a small hole in the soil and retaining the excavated soil in an air tight container for later weight and moisture determination. The hole is then filled with a fluid-filled balloon. The volume of fluid needed to fill the hole is read on a graduated scale. The density is calculated by relating either the dry or wet weight of the soil sample that is removed to the volume of the hole.

This test method can be used to determine the in-place density and unit weight of natural inorganic soil deposits, soil-aggregate mixtures, or other similar firm materials. The use of this test method is generally limited to soil in an unsaturated condition and is not recommended for soil that are soft or that deform easily. Such soils may undergo a volume change during the application of pressure during testing. This test method may not be suitable for soils containing crushed rock fragments or sharp edge materials which may puncture the rubber membrane.

The volumeter method is destructive in nature and rather time consuming. The test also requires calibration to guarantee the accuracy of reading. The main source of error might come from the fact that the volume reading might not accurately represent the actual volume of the sample. This difference might happen due to the inability of the balloon to fill the hole if rocks or coarse materials exist or due to the deformation of soft soils under pressure imposed during the test.

3.3 Sand Cone Method

The sand cone method (ASTM D1556-82,AASHTO T191-82,ARIZ 230) can be summarized in digging out a small hole in the soil and retaining the excavated soil in an air tight container for later weight and moisture determination. A dry, uniform sand calibrated as to the density it assumes when poured from a standard container is used to fill the hole. With the determination of the weight of the sand used, the hole volume can be computed. The density of the soil can be computed by knowing the weight of the soil sample and volume of the hole.

The sand cone method provides good results and has been traditionally accepted by many engineers. On the other hand, the method is time consuming and destructive in nature. Also, the use of the method is generally limited to soil in an unsaturated condition. This method is not recommended for soils that are soft or friable (crumble easily) or in a moisture condition such that water seeps into the hand-excavated hole. The accuracy of the test may be affected for soils that deform easily or that many undergo a volume change in the excavated hole from standing or walking near the hole during the test.

4. PREVIOUS RESEARCH

A large number of research projects were performed in order to compare nuclear density measurements with conventional methods especially the rubber balloon (volumeter) and the sand cone methods. Most of this research effort was conducted in the 1960's and 70's when the nuclear gauges were relatively new. Some of the research results were published in national journals while the majority of the research results were locally available in various state highway departments. In most cases highway agencies were mostly interested in evaluating the accuracy and reliability of nuclear gauges as compared to the volumeter and sand cone methods.

The literature related to nuclear gauges evaluation can be divided to two topics. The first topic is for nuclear density measurements of soils and soil-aggregate mixtures, while the second topic is for nuclear density measurements of asphaltic mixtures. In this report, the literature review concentrates on nuclear density measurements of soils and soil-aggregate mixtures only. In the following paragraphs selected references directly

related to the problem statement of this study are summarized. The bibliography includes additional references related to the use of nuclear density measurements and moisture contents of soils and soil-aggregate mixtures. The results of the Transportation Research Information System (TRIS) computer search are shown in Appendix I.

A comparison between nuclear density and volumeter density was performed by Ralston and Andy (39). Figure 6 obtained from the study report shows that the data scatter is affected by the type of device. The difference between nuclear density and volumeter density could be in the order of 20 pcf with the devices manufactured in the early 1960's. A similar comparison between nuclear density and sand cone density was conducted by Weker (45) as shown in Figure 7. A fairly good correlation was obtained in this study when an individual calibration curve was used for each soil type. In this study it was concluded that using an individual calibration curve for each type of soil would be required in order to achieve good accuracy.

NCHRP Report 43 (18) describes the factors that influence the accuracy of nuclear density gauge measurements and methods that can be used for their reduction. The primary sources of error were identified as (a) inaccurate calibration techniques, (b) sensitivity to soil composition, and (c) sensitivity to surface roughness. The first two sources of error apply about equally to both direct-transmission and backscatter-type gauges. The surface roughness problem is considerable for backscatter-type gauges and almost negligible for the transmission type. The report describes a mathematical model technique for preparation of calibration curves of suitable accuracy for highway construction control for identifiable soil types, thus making it possible to practically eliminate the first two sources of error. However, it was also found that a dual-gauge technique was equally effective and did not

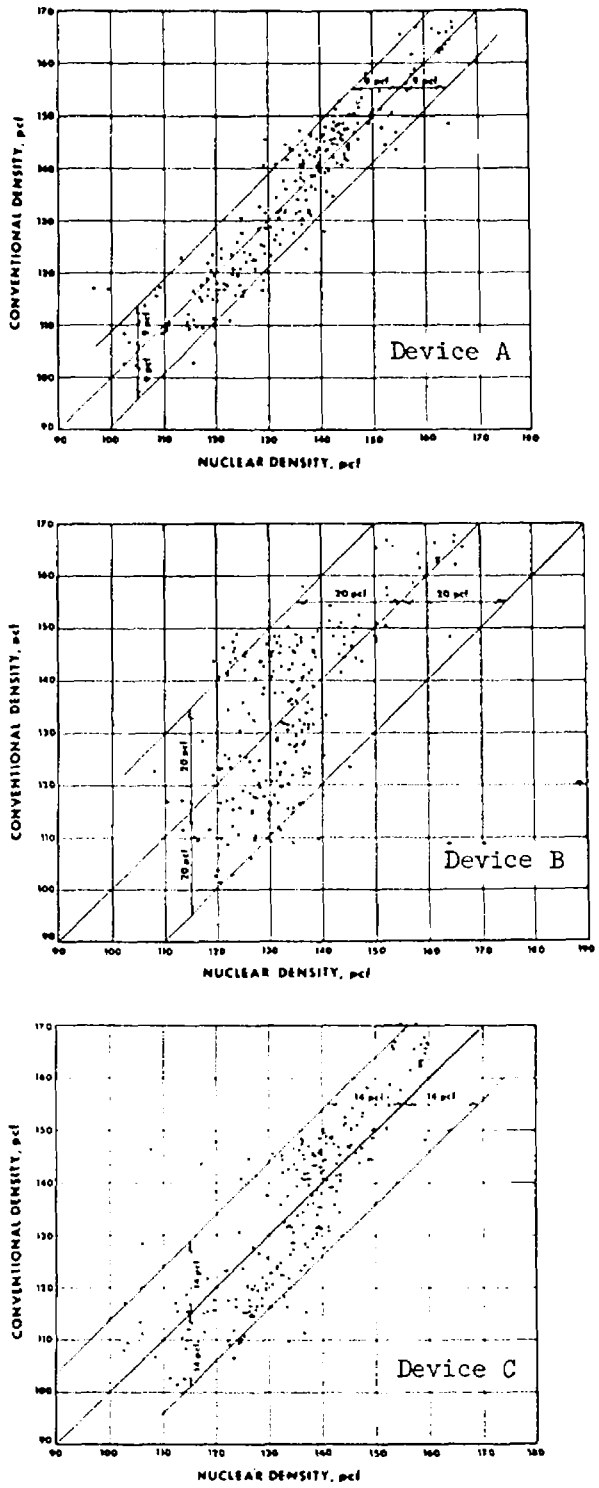


Figure 6. Nuclear densities vs conventional densities (39)

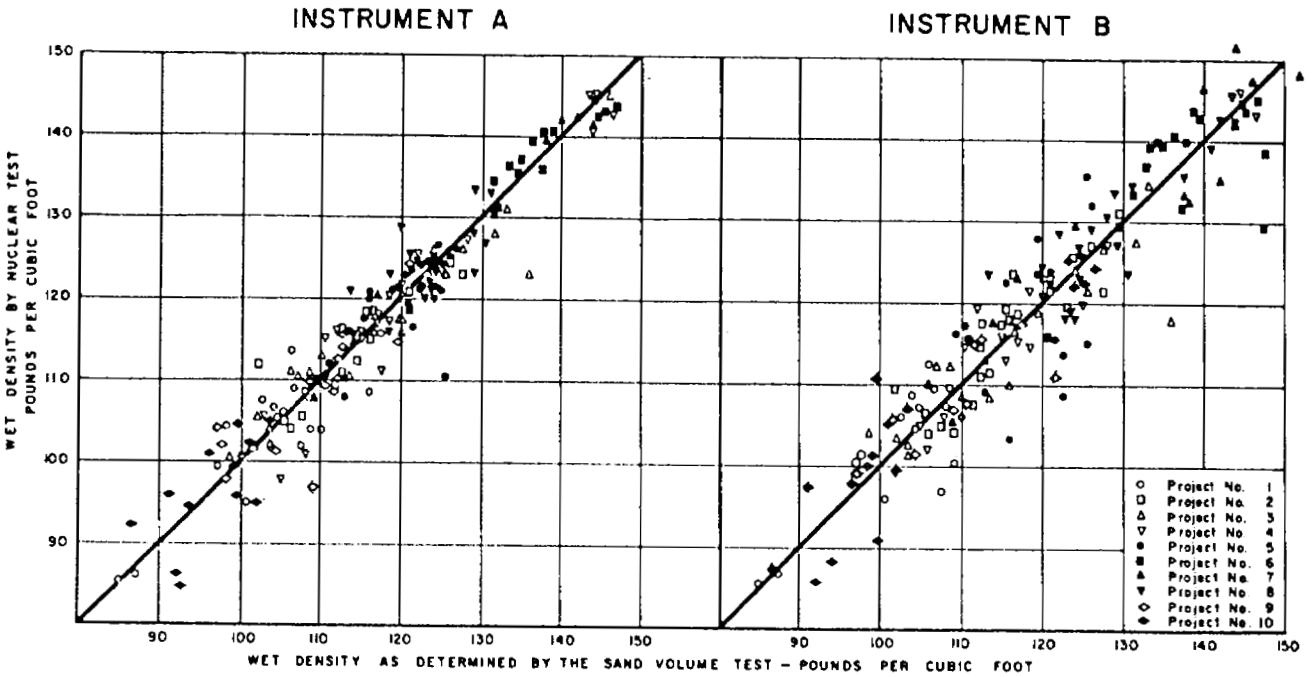


Figure 7. Comparative sand cone and nuclear densities using individual calibration curve for each soil type (45)

require knowledge of the soil composition. This dual-gauge technique consists of using two gauges, each with a different relative sensitivity to soil density and composition, and solving the calibrations models of each simultaneously. A nomograph solution of the air-gap calibration method, which employs the dual-gauge principle, is included in Appendix A of NCHRP Report 43. It was recommended as the most practical method for using existing nuclear density gauges.

Determination of the dry density of the soil or aggregate materials being placed, which is necessary for computing percent compaction, depends on a reasonably accurate method for measurement of moisture content. When nuclear equipment is used to determine total density, the same equipment is normally used to measure the moisture content of the soil. According to NCHRP Report 43, nuclear moisture content gauges are sensitive to variations in soil density and to soil composition. However, the accuracy of these gauges has not been questioned to the same extent as that of density gauges, probably for the reason that a greater percent error of moisture content can be tolerated. When the moisture content of the soil is about 10 percent, 10 percent deviation from the mean will result in a possible error of only 1 pcf.

A laboratory study was conducted by the U.S. Army Engineer Waterways Experiment Station (WES) to evaluate the accuracy and reliability of measuring surface in-site soil density and water content by the direct transmission and backscatter nuclear methods (40). The tests were performed on boxes of soils which were uniformly compacted to a known density. Five soil types were selected for testing representing a wide range of materials; heavy clay (CH), lean clay (CL), sand (SP), clayey gravelly sand (SP-SC), and a well-graded crushed limestone. Each of these soils was tested at eight different densities and water contents. Figures 8 and 9 show the nuclear density and

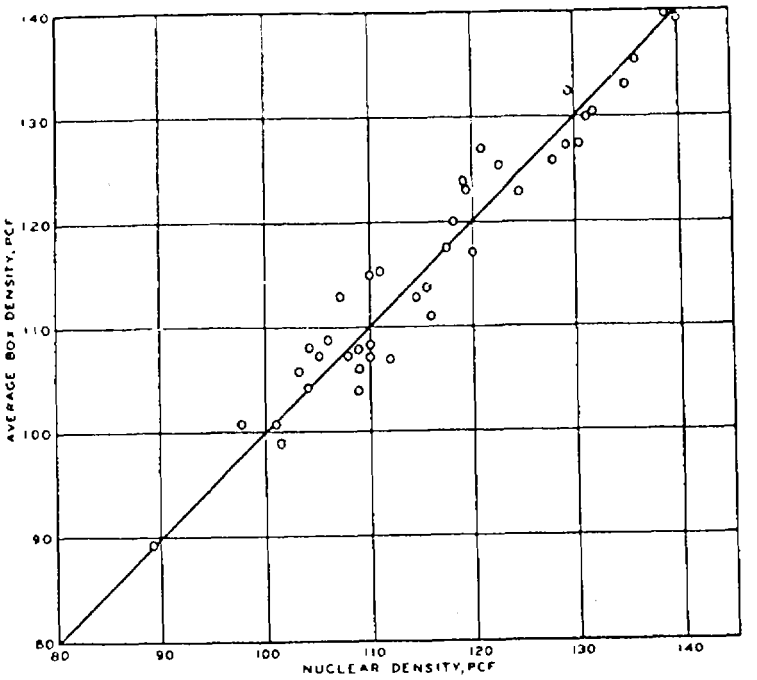


Figure 8. Average box density vs direct transmission nuclear density (40)

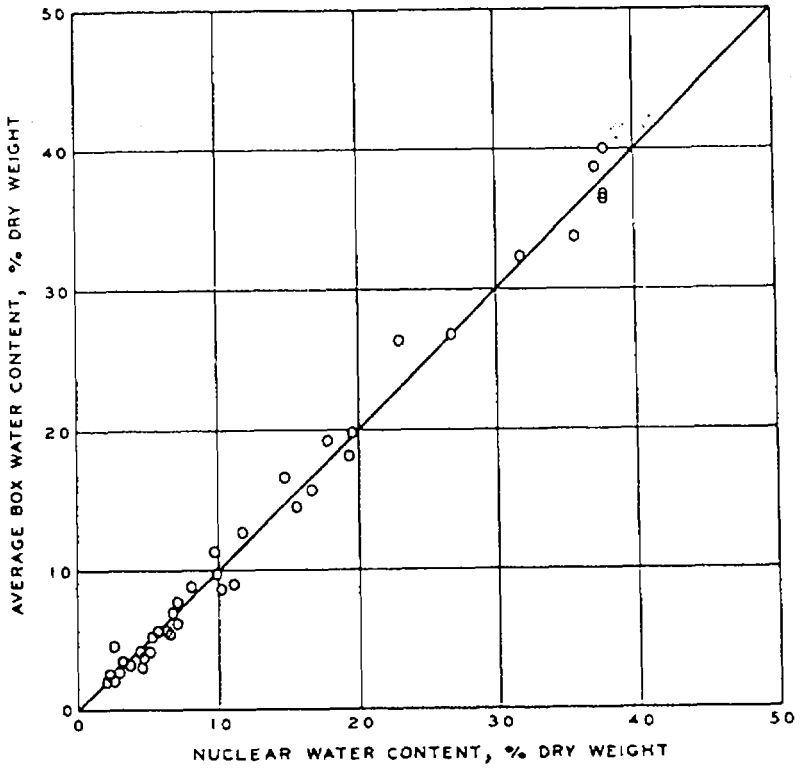


Figure 9. Average box water content vs nuclear water content (40)

moisture content versus the box density. The densities using both the volumeter and sand cone method versus the box density are also shown in Figures 10 and 11. The study concluded that the direct transmission nuclear method using a WES-developed calibration curve provided slightly more accurate density measurements than either the volumeter or sand cone method. The calibration curve developed by WES for local soils provided better results than the factory calibration curve. On the other hand, densities determined by the backscatter nuclear method were less accurate than those obtained by the conventional methods. Moreover, the water contents obtained by the nuclear method using the WES-developed calibration curve were sufficiently accurate for most quality control fieldwork (68% of nuclear water contents were within ± 1.23% of actual water contents, and 95% were within ± 2.46%).

A study was performed in North Dakota to measure the variability of percent compaction and moisture content of compacted embankments in acceptable highway construction projects (30). Randomly located samples were taken on each of three typical construction projects. At each sample location, the following duplicate samples were taken: (a) in-place density using the water-balloon method; (b) in-place moisture by drying two soil samples; (c) moisture and density using a nuclear moisture-density gauge in both direct transmission and backscatter positions; and (d) a sack sample for determination of maximum density. The study concluded that the nuclear instrument, when in the direct transmission position, is a much more reliable indicator of field density than when in a backscatter position and is slightly more reliable than the conventional water-balloon tests and also the air-gap procedure was more reliable than the standard block only on the project believed to have a larger variation in chemical content of the soil.

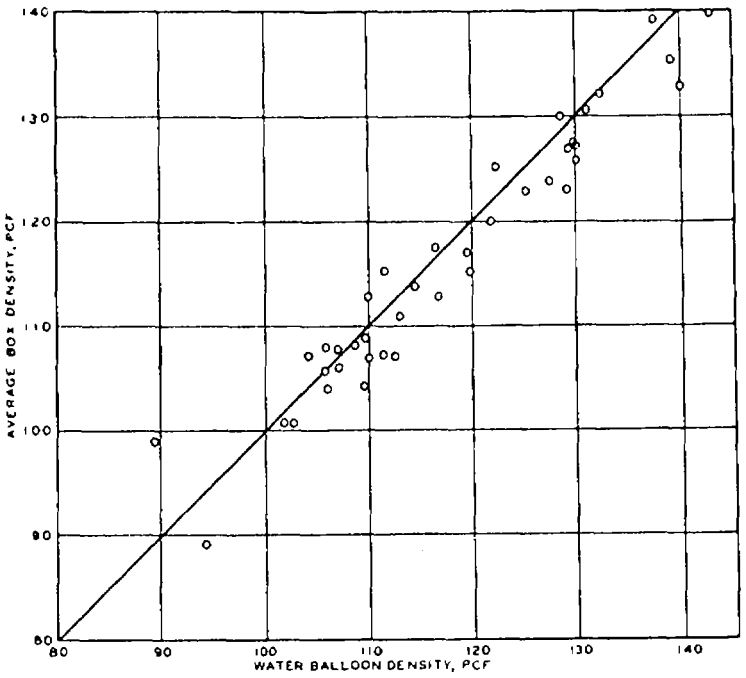


Figure 10. Average box density vs water balloon density (40)

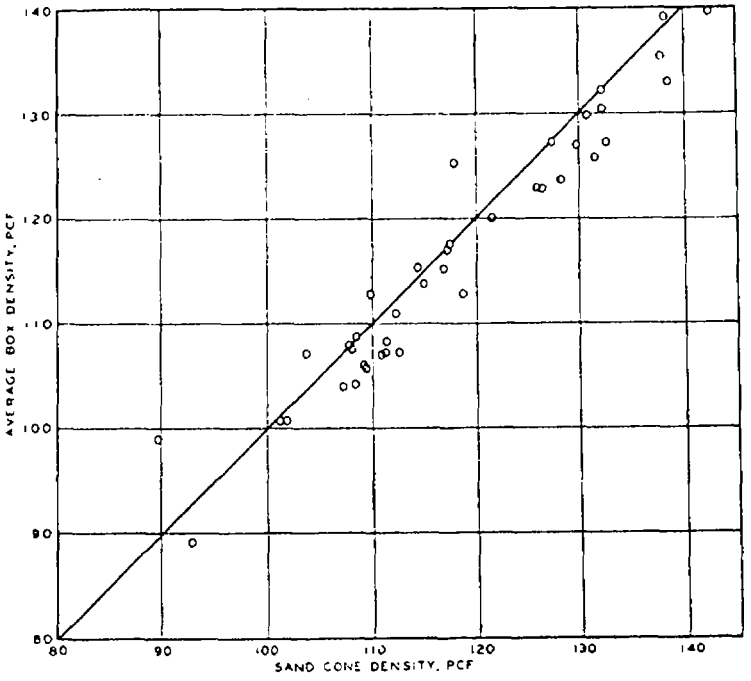


Figure 11. Average box density vs sand cone density (40)

In a study by Gardner (20) the sources of error in the nuclear soil density gauges were identified as sensitivity to variations in sample composition, poor calibration technique, and sensitivity to surface heterogeneities. The errors associated with the nuclear moisture content gauges are identified as sensitivity to soil composition, sensitivity to soil density, and poor calibration technique. Several approaches are described and evaluated for minimizing these sources of error, including mathematical analyses of the nuclear gauging principles, the calibration model method, and the dual-gauge principle for nuclear density gauges.

In the study conducted by Alabama State Highway Department (25) the nuclear soil density gauge measurements were compared to the wet unit weights measured by the sand cone method in the field and a calibrated box mold in the laboratory. The standard errors of estimate were 4 to 5 pcf for all analyses. Very good correlations were obtained in the limited laboratory study. Data indicated that the nuclear density gauge measurements were affected by variations in material composition and that a separate calibration curve for each soil was necessary. The surface nuclear soil density gauge and measurement procedures were not recommended for construction compaction control for embankment or subgrade soils. If this type of gauge is to be used, it was recommended that the air gap procedure be used and that separate calibration curves be established for each soil. The nuclear soil moisture gauge measurements were compared to moisture contents determined by oven drying. The standard errors of estimate were 1.0 pcf or less. Data indicated that a single calibration curve for the determination of moisture content by the nuclear gauge would be satisfactory for most soils.

Another study was conducted by the California Division of Highways in the late 1960's (41). The objectives of this study were: (a) to study the effect of more than 10% of plus 3/4-inch rock fragments on soil density and moisture as determined by nuclear gauges; (b) to study the effect on nuclear moisture determinations when corrugated metal pipe, structural plate pipe, and portland cement concrete are in close proximity to the nuclear gauge. Nuclear moisture and density measurements were taken on samples of roadway excavation and structure back fill from various locations throughout the state under a variety of field and laboratory test conditions. Increasing percentage of plus 3/4-inch rock did not affect nuclear moisture content, dry density or percent relative compaction in any systematic manner. Data obtained confirms that the sand volume method is no more reliable than the nuclear gauge method when wet densities are compared with the measured wet weight unit volume of soil obtained by direct measurements. The depth of nuclear gauge below the surface of surrounding soil and the proximity of a concrete structure to the gauge both affect nuclear moisture determinations. Horizontal clearance around the gauge was also found to affect nuclear readings, but to a lesser degree than the depth variable.

Another study was performed and reported in NCHRP Report 125 (17) to minimize the errors identified with measurement of density and moisture content of soils using nuclear gauges. In approaching the problem of optimization of density gauges the researchers recognized the need to consider the interaction of all possible errors. For example, the best gauge configuration or technique for minimizing the surface roughness errors might result in an increase in errors influenced by composition. To provide a

reasonable basis for optimization, the errors were combined to yield a single criterion, the Quality Factor, which can be used to evaluate the over-all performance of a nuclear density gauge. Research aimed at minimizing moisture content measurement errors involved using the Monte Carlo or random walk method to simulate gauge response, checking the results of the simulation against experimental studies, and attempting to generalize the Monte Carlo results.

The NCHRP study verified that, with proper calibration, currently available nuclear equipment for measurement of density and moisture content provides satisfactory accuracy for the control of compaction of highway embankments and base courses when used within the concept of random sampling and statistically based quality assurance programs. It also provided the Quality Factor as a means for evaluating the performance of existing nuclear gauges and methods to refine the calibration of gauges when improved accuracy is desired.

In a study conducted by the Missouri State Highway Commission (16) results obtained by a nuclear moisture-density gauge were correlated to those obtained by a balloon type volume device and oven drying. The nuclear testing modes were direct transmission for wet density and backscatter for moisture. Comparison tests were made on active construction projects in each of 10 soil types and graded aggregate bases from 10 stone formations. The test sites were located throughout the state. The test results were analyzed statistically by regression, correlation coefficient and t-test (comparison of the means). It was found that the manufacturer's wet density calibration curve provided acceptable results in all of the Missouri soil types and stone formations

tested but that the manufacturer's water calibration curve frequently furnished unacceptable values for moisture content. However, acceptable moisture content values were obtained with the nuclear gauge by use of a computed correction factor. This factor was found to be constant for each particular soil type or stone formation on a project.

A comparative study was performed by Ishai and Liuneh (29) to evaluate the accuracy of in-site nuclear density and moisture content testing. Conventional sand cone and oven-drying tests, as well as tests with different variations of nuclear gauge readings, were performed on trial sections during construction of highway and airport pavements. The results reflected typical subgrade, subbase and base course materials. Statistical analysis was applied to both methods for each testing and site combination. The accuracy and repeatability of results were discussed and compared. The material presented cannot lead to the unequivocal conclusion that the nuclear method for density and moisture content measurement is more accurate than the conventional, since in the sand cone and oven-drying test it is impossible to repeat the test at the same point location but only at an adjacent point. This leads of course to a natural variability because of material composition and processing. On the other hand, it was quite obvious that repeatability in nuclear testing was quite high and fully justifies its practical use. As a result of the speed and ease of nuclear testing, it was preferable to increase its accuracy and reliability by performing a number of tests at the same location or hole. In addition, for the same reason, it was suggested that the average of three readings be taken after rotating the gauge by 120 degrees. The above findings and conclusions were fully verified by the analysis of extensive field density testing performed during the quality control of the construction of Duvda and Ramon airports in southern Israel.

Nuclear density and moisture tests were performed on certain gravel bases in Arkansas and correlated with conventional methods (34). The nuclear method presented inconsistent results when applied to density and moisture of a gravel base material in the Southwest, AR, Nashville area. Nuclear wet densities were lower (4-18 pcf) than the sand cone wet densities. Nuclear moistures appeared to be higher than the oven dry moisture. The gravel base being tested presented high field dry densities (sand cone method) in the range of 133 to 150 pcf. The nuclear gauge in use was a Troxler 3411-B model. In order to investigate the correlation between nuclear and actual density and moisture, and to develop new correlation between curves, six gravel base samples (1.1 cu. ft.) were compacted in the laboratory, and nuclear tests performed on them. The actual density (weight/volume) and the oven dry moisture was compared to the nuclear density and moisture. A correlation study between laboratory nuclear and actual results showed (a) that the correlation nuclear-actual wet density is linear and the difference between them increases as wet density increases; (b) that nuclear moisture can be lower as well as higher than the oven dry moisture and the correlation between them is linear also; (c) that nuclear-actual dry density correlate very poorly. New density and moisture calibration curves for the Nashville, AR, gravel base are presented.

The use of nuclear gauges to determine the moisture content was evaluated in many studies (2,11,14,26,44). The error reported in these studies was in the order of 0.6-3 pcf. In most cases it was concluded that this error is acceptable for compliance testing. It was also concluded that some gauge models provide better results than others and proper calibration is needed in order to achieve good accuracy.

5. CURRENT PRACTICE

In this study a telephone survey was conducted to evaluate the current practice of various state DOT's and highway agencies. Thirty one states including Arizona in addition to the U.S. Corps of Engineers (WES) contacted in this survey. Specific information was secured in the telephone survey as shown in the survey form in Appendix II. Additional information and/or research reports that are related to this study were also requested. A summary of the survey results is shown in Table 1.

A general look at Table 1 shows that most of the states are currently using nuclear gauges as a primary tool for acceptance of density of soils and soil aggregate mixtures in the field. Twenty six out of thirty one states are using nuclear gauges for acceptance of soil density either solely or together with conventional methods. Only 4 states and the U.S. Corps of Engineers indicated that they are using either the volumeter or the sand cone methods only.

State personnel that are currently using nuclear gauges for acceptance of soil density indicated that they are reasonably accurate , faster to use and accepted by both state personnel and contractors. Most of these states indicated that they are depending only on nuclear gauges for many years and they have good experience with them. They are routinely calibrating

Table 1. Summary of the Telephone Survey

State/ Agency	Primary Method Used for Acceptance of Soil Density			Nuclear*		Notes
	Nuclear	Volumeter	Sandcone	B	DT	
Alabama	x				x	
Arizona		x				
California	x				x	
Colorado	x				x	Error $\leq$ 1 pcf
Connecticut	x			x	x	
Florida	x				x	100% nuclear
Georgia	x				x	
Idaho	x			x	x	
Illinois	x				x	
Indiana			x			Nuclear study is underway
Kansas		x	x			
Kentucky	x				x	
Main	x		x		x	
Maryland	x				x	
Massachusetts	x				x	
Michigan	x				x	
Minnesota[2]	x		x		x	
Montana	x			x	x	
Nevada	x				x	
New Mexico	x				x	100% nuclear
New York	x	x	x		x	Nuclear study is underway
North Dakota		x				
Oklahoma	x				x	Almost 100% nuclear
Oregon	x				x	Almost 100% nuclear
South Carolina	x				x	Almost 100% nuclear
South Dakota[3]	x	x	x		x	
Texas	x	x			x	80% nuclear
Utah	x				x	Almost 100% nuclear
Virginia	x				x	
Wisconsin	x			x		100% nuclear
Wyoming			x			
U.S. Corps of Engineers			x			

Notes:

1. B = Backscatter, DT = Direct Transmission.
2. In Minnesota, for soils only the sand cone method is used, but for granular bases and subbases both nuclear and sand cone methods are used.
3. In South Dakota, for soils both volumeter and sand cone are used, but for base courses nuclear gauges are used.

their gauges using soil blocks as recommended by the manufacturers. Some states occasionally verify their gauges against the volumeter or the sand cone method. Other states indicated that they are using the conventional methods only when there are disputes in certain cases. Also, a few states indicated that they are using nuclear gauges about 80% of the time and conventional methods 20% of the time. These states also indicated that gradually they are moving towards the exclusive use of nuclear gauges.

Most of the states that are currently using nuclear gauges for acceptance indicated that they had previously performed correlation studies between nuclear densities and densities obtained by other methods. These correlation results were generally favorable. Most of these studies were performed in the 1960's and 70's and the results were either published in national journals or they were kept within the state. Some of these states follow the manufacturer operational procedure and calibration curves, while others have developed their own procedure and calibration curves. Also, most of these states use both manufacturer training and in-house training. No health problems due to the use of nuclear gauges were reported in the survey.

The majority of the states that are currently using nuclear gauges for acceptance own different models of Troxlar gauges. Some states, however, indicated that they have Campbell or Seaman gauges. Also, the majority of these states use the direct transmission technique for soil density, while very few states use backscatter or both backscatter and direct transmission techniques.

The states that do not currently use nuclear gauges for acceptance of soil density indicated that the nuclear results are suspected, the correlations with conventional methods are poor, and/or the calibration procedure is troublesome. They also indicated that they take soil samples for soils identification in any case, thus, conventional methods would help for this purpose.

Some states such as Indiana and New York are currently performing studies to evaluate the accuracy of nuclear gauges.

As far as the moisture content determination is concerned, many of the states that were contacted are not favoring the use of nuclear gauges for this purpose. They indicated that nuclear gauges do not provide accurate results especially with some types of soils. Some of these states are using nuclear gauges for moisture content determination with caution by adjusting the results using calibration factors for different types of soils. Other states indicated that they are using nuclear gauges for moisture determination without any reservations.

The Troxler Electronic Laboratories, Inc. was contacted and a price list and some brochures were requested. The price list indicates that the base price of the soil moisture/density nuclear gauge ranges between $4,000 and $5,500 in addition to the price of the necessary accessories.

6. SUMMARY AND CONCLUSIONS

The majority of acceptance specifications or quality assurance procedures for controlling the compaction of highway embankments, subgrades and base courses involve the determination of densities and moisture contents of soil and aggregate materials during the construction process. Nuclear gauges for making these measurements first became available in the late 1950's. Although

the gauges seemed to answer a need for rapid and nondestructive testing, growth in their acceptance and use has been rather slow until the 1960's and 70's, due largely to questions concerning measurement accuracy. Early experiences with regard to field reliability, economics, radiation, and licensing of operators also tended to discourage the use of nuclear equipment by highway departments, but these problems appear to have been overcome in recent years (17).

The main advantage of nuclear gauges is that they are rapid and nondestructive. They also offer greater degree of freedom from human error and require less judgement on the part of the operator. On the other hand, the main disadvantage of nuclear gauges is the accuracy of the density and moisture content results. Since the nuclear results are indirect, calibration relations have to be developed. Calibration curves developed for a specific type of soil or aggregate might not be valid for other types of materials. Also, nuclear density or moisture content is not necessarily the average density or moisture content within the volume of the material involved.

Most of the studies comparing nuclear densities with volumeter and sand cone densities have been performed in the 1960's and 70's. Most of these studies concluded that nuclear densities are generally not less accurate than the volumeter or the sand cone densities. Although the correlations are not excellent, there is no reason to believe that one method is more accurate than the other. Each method has its advantages and drawbacks. According to ASTM standards, "No methods are available that provide absolute values of the density of soil or soil-aggregate mixtures in place against which these (nuclear) methods can be compared." "Accuracy is a function of the case exercised in performing the calibrations and steps of the test and of the variability of the material being tested."

Based on the telephone survey conducted in the study, most of the states which were contacted are currently using nuclear gauges for acceptance specifications or qualify assurance for controlling compaction of subgrade, subbase, and base courses. These states are generally satisfied with the density results obtained from nuclear gauges. The use of nuclear gauges for density control of soil and aggregates seems to be increasing. Some of these states indicated that they are using conventional methods only in cases of disputes or disagreements. The contractors also seem to be satisfied with these nuclear gauges and many of the contractors have their own gauges. Only a few states in addition to the U.S. Corps of Engineers are using the volumeter or the sand cone method for acceptance control. Other states are using both nuclear gauges and conventional methods for acceptance. Also, the direct transmission method is predominantly more used than the backscatter or the air gap methods.

The use of nuclear gauges for moisture content determination seems to be less frequent than their use for density determination. Many states indicated that nuclear gauges are not very accurate for moisture content determinations. Many of these states prefer to use the SPEEDY moisture content method over nuclear gauges. Some states, however, are satisfied with the use of nuclear gauges for the determination of the soil moisture content.

Although nuclear gauges are used in Arizona, they have not been used for acceptance control. The main concern is related to their accuracy and variability of the results. A research study is recommended to compare the density and moisture content results obtained by nuclear gauges to those obtained by the volumeter and sand cone methods. The following section outlines a plan for such a study that could be performed by ADOT.

7. RECOMMENDATION FOR FURTHER RESEARCH

In order to evaluate the accuracy and reliability of nuclear gauges for the determination of density and moisture content of soil and soil-aggregate mixtures a study has to be conducted using typical Arizona materials. The following steps outline the recommended study procedure.

a. Select 5-7 typical types of soil and soil-aggregate mixtures from Arizona.

b. Compact these materials as uniformly as possible in boxes in the lab at 10-15 different densities and moisture contents. The average density of the material is obtained by knowing the soil weight and volume. The moisture content is obtained by oven drying some samples and also by the SPEEDY test.

c. Perform nuclear density and moisture content tests on the lab compacted materials using the direct transmission method. The backscatter method can also be used if necessary. Since the nuclear test is relatively simple and fast, several replicate tests should be performed. Also, different gauge models can be used for comparison.

d. Perform the volumeter (rubber balloon) test on the lab compacted materials. The sand cone test can also be performed if necessary.

e. Select several sites in the field and perform nuclear, volumeter, sand cone density tests. Determine the in-site moisture content using both oven drying and SPEEDY methods.

f. Analyze the results as follows:

1. Compare lab nuclear density with the average block density.
2. Compare lab nuclear density with densities obtained from the conventional methods in the lab.
3. Compare lab nuclear moisture content with those obtained from oven drying and SPEEDY tests in the lab.
4. Compare field nuclear density with field densities obtained from conventional methods.
5. Compare field nuclear moisture content with field oven drying and SPEEDY test results.

Perform statistical analyses and evaluate the accuracy and variability of nuclear gauges as related to the average block lab results and results obtained from conventional methods.

g. Determine the significance and reliability of the use of nuclear gauges under various conditions and for various materials. Finally a recommendation has to be derived as to whether to use or not to use nuclear gauges for acceptance specifications in Arizona for both density and moisture content determinations.

BIBLIOGRAPHY

1. Ballard, L.F., and Gardner, R.P., "Density and Moisture Content Measurements by Nuclear Methods-Interim Report." NCHRP Rep. 14, 1965.

2. Ballard, L.F.,"Instrumentation for Measurement of Moisture: Literature Review and Recommended Research." NCHRP Rpt. 138, 1973.

3. Belcher, D.J., Cuykendall, T.R., and Sack, H.S., "The Measurement of Soil Moisture and Density of Neuton and Gamma-Ray Scattering." Tech.Dev.Rep.No.127, U.S. Civil Aeronautics Admin., 1950.

4. Belcher, D.J., Cuykendall, T.R., and Sack, H.S.,"Nuclear Meters for Measuring Soil Density and Moisture in Thin Surface Layers." Tech.Dev. Rep. No.161, U.S. Civil Aeronautics Admin., 1952.

5. Benson, P.E., and Kuhl, D.J.,"Precision of the Relative Compaction Test Using Nuclear Gauges." Rpt. No. FHWA/CA-76/1153, California DOT, Dec. 1976.

6. Blackwell, P.L., Brown, W.R., and Rizenbergs, R.L.,"Survey of Current Use of Nuclear Gauges in the Highway Field." HRB, Circ. No. 85, 1968.

7. Carlton, P.F., "Application of Nuclear Soil Meters to Compaction Control for Airfield Pavement Construction." Symposium on Nuclear Methods for Measuring Soil Density and Moisture, ASTM Spec. Tech. Pub. No. 293, 1961.

8. Chen, E.[illegible]. et al.,"Improved Nuclear Gauge Development, Phase I and II." Rpt. No. CA-DOT-TL2857-1-76-45, California DOT< Sept. 1976.

9. Chan, E.E., et. al.,"Improved Performance Criteria for Use in Nuclear Gauge Specifications." Rpt. No. CA-DOT-TL-210817521, California DOT, May 1975.

10. Choy, G.,"Evaluation of Test Method for Density of Soil Aggregate In-place by Nuclear Gauge." Hawaii DOT, 1986.

11. Ciftcioglu, O., Byatt, D.A., and Taylor, D.,"Determination of Moisture Content with a Gamma Backscatter Density Gauge." Journal of Soil Science, Vol. 23, No. 1, March 1972.

12. Cotecchia, V., and Pirastru, E.,"Development of Nuclear Methods for Measuring Density and Natural Water Content of Soils." Nuclear Science Abstracts, Vol. 26, No. 8, April 1972.

13. Csathy, T.I.,"Nuclear Methods for Determining Density and Moisture Content--A Review of the Literature." Rep. No. 30, Ontario Dept. of Highways, Toronto, 1962.

14. Couchat, et. al.,"Automatic Neutron Device for Measuring the Moisture Content of Soil." Bulletin d'Informations Scientifiques and Techniques, N172, July 1972.

15. Dunn, W.L., and McDougall, F.H.,"Minimizing Errors in Gamma-Ray Surface-Type Density Gauges: Existing Gauges and New Design Concepts." HRB, Record 301, 1970.

16. "Field Evaluation of a Direct Transmission Type Nuclear Moisture-Density Gauge." Missouri State Highway Commission, Division of Materials and Research, Jefferson City, Missouri, Jan. 1975.

17. Gardner, R.P., Dunn, W.L., McDougall, F.H.,and Lippold,W.J.,"Optimization of Density and Moisture Content Measurements by Nuclear Methods." NCHRP Rep. 125, 1971.

18. Gardner, R.P., and Roberts, K.F.,"Density and Moisture Content Measurements by Nuclear Methods--Final Report." NCHRP Rep. 43,1967.

19. Gardner, R.P.,"Elimination of Measurement Interferences from Surface-Type Nuclear Soil Density and Moisture Gauges." Trans. American Nuclear Society Topical Meeting on Radiation and Isotope Technology in Latin American Development, San Juan, P. R., May 1969.

20. Gardner, R.P.,"Minimizing Nuclear Soil Density and Moisture Content Gauge Errors." HRB, Record 290, 1969.

21. Gardner, R.P., Roberts, K.F., Hughes, C.S., and Anday, M.C.,"A Calibration Model for Optimizing the Air-Gap Method of Compensating Nuclear Density Gauges for Soil Composition Variations." Journal of Materials, Vol. 2, No. 1, 1967.

22. Gnacdinger, J.P.,"A Statistical Study of Variations in Materials and Compacted Densities by Sand-Cone and Nuclear Methods." Journal of Materials Vol. 6, No. 4, Dec. 1971.

23. Hinucker, G.L.,"Nuclear Methods of Measuring Moisture and Density of Soils." Assn. of American Railroads Research Center, AREA Bulletin, Vol. 65 N586, July 1964.

24. Hoffmeyer, C.K.,"Control of Compaction by Nuclear Density Meters." Ohio River Division Laboratories, U.S. Army Corps of Engineers, 1958.

25. Holman, F.L., Eiland, E.N., and McCullough, W.F.,"Compaction Measurements by Nuclear Devices." HPR Rpt. 34, Alabama DOT, June 1962.

26. Horonjeff, R., and Javite, D.F.,"Nutron and Gamma-Ray Methods for Measuring Moisture Content and Density to Control Field Compaction." HRB, Bulletin 122, 1955.

27. Hughes, C.S., and Anday, M.C.,"Correlation and Conference on Portable Nuclear Density and Moisture Systems." HRB, Record 117, 1967.

28. "Instrumentation and Equipment for Testing Highway Materials, Products, and Performance." NCHRP Synthesis for Highway Practice No. 36, 1976.

29. Ishai, I., and Liunch, M.,"Comparative Accuracy of In-site Nuclear Density Testing." Southeast Asian Society of Soil Engineering, Geotechnical Engrg., Vol.14, No. 1, June 1983.

30. Jorgenson, J.L.,"Measuring the Variability of Compacted Embankments." HRB, Record 190, 1969.

31. Krebs, R.D., and Walker, R.D.,"Highway Materials." McGraw-Hill, 1971.

32. Kuhn, S.H.,"The Effects of Type of Material on Nuclear Density Measurements." HRB, Record 66, 1965.

33. Leary, D.J., and Woodward, R.J.,"Experience with Relative Density as a Construction Control Criterion." ASTM, Special Technical Publication N523, July 1973.

34. LeFevre, E.W.,"Evaluation of Correlation between Nuclear Moisture/Density Tests and Standard Tests on Certain Gravel Bases in South Arkansas." FHWA, Final Report Np. FHWA/AR-85/005, 1984.

35. Portridge, T.B., and Rigden, P.J.,"Developments in Radioisotope Measurement of Soil Moisture Content and Density." HRB, Bulletin309, 1962.

36. Mainfort, R.C.,"Development of Nuclear Methods for Q.C. of Highway Embankment Construction." Rpt. 61 E-22, Michigan DOT, 1961.

37. McDougall, F.H., Dunn, W.L., and Gardner, R.P.,"Report on Nuclear Soil Gauge Calibration Workshop-Symposium." Unpublished report from North Carolina State University, April 1969.

38. Preiss, K.,"Analysis and Improved Design of Gamma-Ray Backscattering Density Gauges." HRB, Record 107, 1966.

39. Ralston, H.H., and Andy, M.C.,"Nuclear Measurement of Soil Properties." HRB, Record 66, 1964.

40. Rosser, T.B., and Webster, S.L.,"Evaluation of Nuclear Methods of Determining Surface and In Site Soil Water Content and Density." Misc. Paper 5-69-15, U.S. Army Engineer Waterways Experiment Station, 1969.

41. Roy, S.E., and Winterkorn, H.F.,"Scintillation Methods for the Determination of Density and Moisture Contents of Soils and Similar Granular Systems." HRB Bulletin 159, 1957.

42. Smith, T., et. al, "Effect of Plus 3/4-inch Rock and Other Field Variables on Nuclear Gauge Moisture and Density Determination." Final Rpt. No. M&R, California Division of Highways, Jan. 1970.

43. Vaswani, N.K.,"Nuclear Measurement of Subgrade Moisture." Rpt. No. 97,Virginia University, School of Engineering and Applied Sciences, Charlottesville, Va., June 1975.

44. Vaswani, N.K.,"Pavement Design and Performance Study; Phase B-Deflection Study: Nuclear Measurement of Subgrade Moisture." Interim Rpt. No. 5, Virginia Highway Research Council, Charlottesvile, Va, Nov. 1973.

45. Webber, W.G.,Jr.,"Laboratory and Field Evaluation of Nuclear Surface Gauges for Determining Soil Moisture and Density." HRB, Record 66, 1964.

46. Wyant, D.C., Andy, M.C., and Hughes, C.S., III, "Refinement of Moisture Calibration Curves for Nuclear Gauge." Final Rpt., Virginia Highway Research Council, Charlottesville, Va. Dec. 1973.

APPENDIX I

RESULTS OF TRIS RESEARCH

EVALUATION OF TEST METHOD FOR DENSITY OF SOIL AGGREGATE IN-PLACE BY NUCLEAR GAGE

INVESTIGATORS: Choy, G

SPONSORING ORG: Hawaii Department of Transportation; Federal Highway Administration

PERFORMING ORG: Hawaii Department of Transportation 869 Punchbowl Street Honolulu Hawaii 96813

CONTRACT NO: HP&R

PROJECT START DATE: ND

PROJECT TERMINATION DATE: 8610

SUBFILE: HRIS

To evaluate the new test method for relative density testing of soil and soil-aggregate in-place by nuclear gage.

DETERMINATION OF THE CORRELATION BETWEEN NUCLEAR MOISTURE/DENSITY TESTS AND STANDARD TESTS ON CERTAIN GRAVEL BASES IN SOUTH ARKANSAS. FINAL REPORT

LeFevre, EW

Arkansas University, Fayetteville Department of Civil Engineering Fayetteville Arkansas 72701; Arkansas State Highway and Transportation Dept 9500 New Benton Highway, P.O. Box 2261 Little Rock Arkansas 72203; Federal Highway Administration 400 7th Street, SW Washington D.C. 20590

1984 n.p.

REPORT NO: FHWA/AR-85/005

SUBFILE: HRIS

AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161

The nuclear method presented inconsistent results when applied to density and moisture of a gravel base material in the Southwest, AR, Nashville area. Nuclear wet densities were lower (4-18 pcf) than the sand cone wet densities. Nuclear moistures appeared to be higher than the oven dry moisture. The gravel base being tested presented high field dry densities (sand cone method) in the range of 133 to 150 pcf. The nuclear gage in use was a Troxler 3411-B model. In order to investigate the correlation between nuclear and actual density and moisture, and to develop new correlation between curves, six gravel base samples (1.1 cu. ft.) were compacted in the laboratory, and nuclear tests performed on them. The actual density (weight/volume) and the oven dry moisture was compared to the nuclear density and moisture. A correlation study between laboratory nuclear and actual results showed (1) that the correlation nuclear-actual wet density is linear and the difference between them increases as wet density increases; (2) that nuclear moisture can be lower as well as higher than the oven dry moisture and the correlation between them is linear also; (3) that nuclear-actual dry density correlate very poorly. New density and moisture calibration curves for the Nashville, AR, gravel base are presented.

IN-SITU DETERMINATION OF MOISTURE IN ROAD PAVEMENT BY NUCLEAR METHODS
Gray, GW; Sowerby, BD; Youdale, GP
Australian Atomic Energy Comm Res Establishment Lucas Heights Australia
Apr 1981 21p
REPORT NO: AAEC/E-511
SUBFILE: NTIS; HRIS
AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161
The use of neutron moisture probes to determine moisture in compacted pavement layers has been studied on samples representative of those used by the New South Wales Department of Main Roads for roadway construction. The aim of this work was to measure the average moisture content of the upper layer (15-20 cm thick) with minimum interference from moisture in underlying layers. Sub-surface probes using high (alpha -Be) and low (alpha -Li) energy neutron sources were examined; conventional alpha -Be sources in specially designed compact probes should result in an error due to base moisture and density variations of less than 0.4 wt % moisture. As this error is probably less than those due to sampling and geometry variations in the field, such a probe should be sufficiently accurate for DMR requirements. If less sensitivity to base moisture is required, the alpha -Li source will reduce this sensitivity by a factor of about 1.4. (Atomindex citation 12:634552) U.S. Sales Only.

LONG-LIFE TREATMENT FOR AILING M6
IPC Building and Contract Journals Limited
Surveyor - Public Authority Technology VOL. 154 NO. 4552 Sep 1979 pp 30-31 7 Phot.
SUBFILE: TRRL; IRRD; HRIS
The necessary reconstruction of 6.5 km of Midlands Link Motorway including two lengths on viaduct and one on embankment is described in this short article. The sequence of operations is described, and the vibratory rolling of both sub base and wearing course to increase the density of materials is noted. On the embankment section, because of water penetration problems, hot rolled asphalt is to replace the original lean concrete base. A Troxler nuclear gauge is in use to achieve accurate and quick density readings for soil, and pavement layers. Failed joints on viaduct are being replaced by cementitious epoxy plus steel fibres bridge joints.

THE CURRENT STATUS OF NUCLEAR TESTING FOR MOISTURE AND DENSITY OF SOILS AND RELATED MATERIALS
Gunderman, WG (Transportation Research Board)
Engineering Geological & Soil Engineering Symp; P. O. Box 7129, 3211 State Street; Boise; Idaho; 83707
Proceeding p 19
SUBFILE: HRIS
This paper reviews, briefly, the history of moisture density testing by nuclear methods. It discusses the problems to be faced by an organization using these methods and equipment and attempts to place them in their proper perspective. It also takes a look at the methods currently in use with which the nuclear methods must compete. A review is made of some of the important work in progress or recently completed, and the author expresses his views of future developments in nuclear testing. Finally there is included a brief summary of moisture density logging.

RADAR MEASUREMENT OF SOIL MOISTURE CONTENT
Ulaby, FT
IEEE Transactions on Antennas and Propagation VOL. AP22NO. 2 Mar 1974 pp 257-265
SUBFILE: BCL; HRIS
The effect of soil moisture on the radar backscattering coefficient was investigated by measuring the 4-8 GHz spectral response from two types of bare-soil fields: slightly rough and very rough, in terms of the wave-length. An FM-CW radar system mounted atop a 75-foot truck-mounted boom was used to measure the return at 10 frequency points across the 4-8 GHz band, at eight different look angles (0 degree through 70 degree), and for all polarization combinations. A total of 17 sets of data were collected covering the range 4-36 percent soil moisture content by weight. The results indicate that the radar response to soil moisture content is highly dependent on the surface roughness, microwave frequency, and look angle. The response seems to be linear, however, over the range 15-30 percent moisture content for all angles, frequencies, polarizations, and surface conditions. /ARTHUR/

QUALITY CONTROL OF COMPACTION IN EARTHWORKS AND PAVEMENTS BY NUCLEAR METHODS
Ferguson, DJ (Steveson (W) and Sons Limited)
National Roads Board, New Zealand; Road Research Unit, P.O. Box 8024; Wellington; New Zealand
VOL. 2 Proceeding pp 452-465 4 Fig. 7 Tab. Apps.
SUBFILE: HRIS
Present density and moisture control methods are fast becoming inadequate, especially with the increased use of high speed, large capacity earth moving and compaction equipment. Speed in the primary advantage of testing by nuclear methods. The result of a test is immediately available to both engineer and contractor. Compaction inadequacies may be corrected immediately before subsequent lifts of material have been laid. Decisions on rejection or acceptance can be made on the spot, and the appropriate action taken before the weather takes a hand in proceedings. In cases of doubt, further tests can quickly be made. If further compactive effort is required, immediate checks can be made to determine whether this has been effective. An invaluable application of nuclear Hidrodensimeters is determination of the moisture content of borrow areas before the material is placed, thus preventing the use of unsuitable materials, eliminating rule of thumb methods, guess work, "getting away with it", and other hopeful measures which are used in a surprising number of cases. Greater coverage of a job is possible, in the form of many more up to date tests within the same time as those recorded by conventional methods. Thus a truer picture of "as built" conditions is provided. The mobility of the equipment makes it possible for several sites to be checked in one day. The testing organization becomes more flexible, as it is not as dependent on static laboratory based equipment. A qualified soil technician is essential for itelligent operation of the instrument, and for intelligent interpretation of results, but total labor requirements are considerably reduced. Applications of the nuclear method not previously discussed, include determination of the density and asphalt content (while still hot) of thick lift asphalt pavements, in place of expensive conventional coring techniques. Greater coverage and non-destructive properties contribute to its value in this application. Evaluation of compaction equipment and

materials in test banks, or in actual site conditions can be readily carried out on the same sites, following subsequent roller passes of smooth wheeled equipment. This non-destructive technique is of great value for investigating the performance of road materials and road rollers. The in situ density of concrete can readily be checked to a high degree of accuracy and rapid moisture determination of timber is possible. In the absence of weight-bridges, the loading of vehicles carrying soils and aggregates can be checked, if the volume of the load is known. In summary, nuclear density and moisture test methods are comparable in accuracy with conventional test methods, and in some applications superior, are more economical on a long term basis, and offer greater coverage, simplicity, and flexibility of operation. Of greatest importance is the ability of these instruments to provide almost instantaneous results of tests. Proceedings of Roading Symposium, 1971, held at Victoria University of Wellington, 17-19 August, 1971.

FINAL REPORT-REFINEMENT OF MOISTURE CALIBRATION CURVES FOR NUCLEAR GAGE
Wyant, DC; Anday, MC; Hughes, CS, III
Virginia Highway Research Council; P.O. Box 3817, University Station; Charlottesville; Virginia; 22903
Dec 1973 Final Rpt.
CONTRACT NO: 0955; Contract
SUBFILE: HRIS
AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22151
The Troxler Model 227 gage had a linear response between the count ratio and the moisture content. Two moisture calibration curves were required to obtain reasonable accuracy (1.4 pcf or 0.02g/cc and 1.7 pcf or 0.03g/cc standard errors). The two curves were best divided by the optimum moisture content of the soil. The separation value of the optimum moisture contents was around 21%. With the more modern Troxler Model 2401 gage only one mositure calibration curve was needed and it had a standard error of 1.7 pcf or 0.03 g/cc/ To produce a moisture calibration curve for another nuclear gage four moisture standards were developed using MgSO4.7H2O or Na3PO4.12H2O mixed with sand. These chemical moisture standards ranged in moisture contents from 9.3 pcf (0.15g/cc) to 25.8 pcf(0.41g/cc). Besides these four standards a zero moisture content standard was developed from dry sand. The moisture calibration curve for the Model 2401 gage from the five standards indicated a standard error of 0.57 pcf or 0.01g/cc. /FHWA/

REFINEMENT OF MOISTURE CALIBRATION CURVES FOR NUCLEAR GAGE
Wyant, DC; Anday, MC; Hughes, CS, III
Virginia Highway Research Counicil; Virginia Department of Highways and Transportation; Charlottesville; Virginia; 22903
Dec 1973 Final Rpt. 25 pp 8 Fig. 2 Tab. 6 Ref.
REPORT NO: VHRC 73-R24
SUBFILE: HRIS
Over the last three years the Virginia Highway Research Council has directed a research effort toward improving the method of determining the moisture content of soils with a nuclear gage. The first task in this research was the determination of the correct moisture calibration curve for the nuclear gages being used (Troxler Models 227 and 2401). Forty-three soils sampled from the three physiographic areas of Virginia and having

optimum moisture contents ranging from 5% to 40% were tested. It was found that for the Model 227 gage two calibration curves produced better results than did one calibration curve. With one curve the standard error was 2.7 pef (0.04 g/cc), while for two curves the errors were 1.4 and 1.7 pef (0.02 and 0.03 g/cc), which are judged to be acceptable for compliance testing. From an investigation of the physical and chemical properties of the soils tested it was concluded that the separation of the two curves could be based on optimum moisture content, and that the separation value should be 21%. At this point in the study, the testing of the Model 227 gage was discontinued because the Virginia Department of Highways had replaced all of these gages with the Model 2401. The Model 2401 gage requires only one calibration curve, which has a standard error of 1.7 pef (0.03 g/cc). Using this gage and its single calibration curve, five moisture standards were developed.

PAVEMENT DESIGN AND PERFORMANCE STUDY; PHASE B--DEFLECTION STUDY: NUCLEAR MEASUREMENT OF SUBGRADE MOISTURE

Vaswani, NK

Virginia Highway Research Council; P.O. Box 3817, University of Virginia Station; Charlottesville; Virginia; 22903

Nov 1973 National Technical Information Service 5285 Port Royal Road Springfield Virginia 22151

REPORT NO: Interim Rpt. No. 5

SUBFILE: NTIS; HRIS

The basic consideration in evaluating subgrade moisture conditions under pavements is the selection of a method of determining moisture contents that is sufficiently accurate and can be used with minimal effort, interference with traffic, and calibrations. In this study, the electrical resistance method and a nuclear method were tried, and the nuclear method was adopted. The devices and procedures used in both methods are described. Modified methods for eliminating errors in the measurement of moisture by nuclear depth probes were tried and some of these are recommended for use. A method of reducing the standard error of estimate in the use of a nuclear calibration curve for moisture content by utilizing the sieve analysis of a soil is discussed.

DETERMINATION OF MOISTURE CONTENT WITH A GAMMA BACKSCATTER DENSITY GAUGE

Ciftcioglu, O; Byatt, DA; Taylor, D

Journal of Soil Science VOL. 23 NO. 1 Mar 1972 pp 32-7 1 Fig 3 Tab 5 Ref

SUBFILE: TRRL; IRRD; HRIS

GAMMA-RADIATION BACKSCATTER GAUGES, AS NORMALLY EMPLOYED FOR THE DETERMINATION OF THE BULK DENSITY OF SOILS, USE INTEGRAL MODE COUNTING. THEY ARE RELATIVELY INSENSITIVE TO THE PRESENCE OF SOIL MOISTURE AND HENCE NOT GENERALLY SUITABLE FOR MONITORING SOIL MOISTURE CONTENT. USING DIFFERENTIAL MODE COUNTING WITH THE WINDOW SET AT ABOUT 0.08 MEV, HOWEVER, THE PHENOMENON IS ONE OF MULTIPLE INSTEAD OF SINGLE SCATTERING. WITH A SOURCE-DETECTOR SEPARATION OF THE ORDER OF 20 CM, ABOUT EIGHT COMPTON INTERACTIONS ARE OBTAINED AND, AS A MULTIPLYING FACTOR OF Z/A IS INVOLVED AT EACH INTERACTION, THE INCREASED RESPONSE WITH HYDROGEN- CONTAINING MATERIAL IS EASILY OBSERVABLE. THIS METHOD CAN THEREFORE BE EXPLOITED TO MEASURE THE MOISTURE CONTENT OF SOILS. THE SENSITIVITY IS HIGH, AND THE ACCURACY IS BETTER THAN PLUS OR MINUS 5 PERCENT, WHICH IS NOT AS GOOD AS CAN BE ACHIEVED WITH A SEPARATE THERMAL NEUTRON DETECTOR, BUT IS USEFUL FOR MANY PURPOSES AND, OF COURSE, ONLY ONE INSTRUMENT IS REQUIRED. /AUTHOR/

DEVELOPMENT OF NUCLEAR METHODS FOR MEASURING DENSITY AND NATURAL WATER CONTENT OF SOILS

Cotecchia, V; Pirastru, E

Nuclear Science Abstracts VOL. 26 NO. 8 Apr 1972 p 1686 ABS 17753

SUBFILE: HRIS

Studies conducted since 1961 to investigate and eliminate interference affecting measurement of the density and natural water content of soils by the nuclear method are reported. Studies based on neutron transport and diffusion theories made it possible to obtain a complete picture of the way in which the measurement of the natural water content is influenced by chemical composition and dry density of the soil. The information thus obtained was applied in building an original epithermal neutron probe incorporating a special helium-3 counter. A review is presented of the fields to which the use of neutron and gamma ray probes have been extended, including measurement of total and partial porosity of soils, and measurement of suspended load in rivers, and of density of materials newly deposited in lakes. /author/

DEVELOPMENTS IN RADIOISOTOPE MEASUREMENT OF SOIL MOISTURE CONTENT AND DENSITY

Partridge, TB; Rigden, PJ

Highway Research Board Bulletin 1962 No 309, pp 85-108, 21 FIG, 4 TAB, 8 REF

SUBFILE: HRIS

The paper describes research and development work carried out on the technique of determining the moisture content of soil by neutron irradiation and density by back-scattering of gamma rays. A new instrument is described that employs A single radium-beryllium source giving both neutrons and gamma rays. The source is used in a single probe for surface work or in a single depth probe for measurements of depth. Some new features in the apparatus include a means of controlling the effective depth of which density is measured and the use of special reflecting devices to increase the sensitivity in moisture determinations. Extensive studies of the volume and depth of soil measured and of the problem of achieving accurate calibration of the instrument over the practical range of moisture content and density are described. Examples of different fields of application of the instrument are given. /author/

THE NUCLEAR METHOD OF SOIL-MOISTURE DETERMINATION AT DEPTH

Texas University, Austin; Ehlers, CJ; Reese, LC; Anagnos, JN

Oct 1968

REPORT NO: 3-5-65-89

SUBFILE: HRIS

Nuclear equipment manufactured by the troxler electronic laboratories, inc. Was used to measure moisture changes at depth at three different test sites. Moisture contents were obtained using the manufacturer's calibration curve, whose accuracy was checked in the field by comparing nuclear and gravimetric results. Effect of air gap, the reproducibility of a neutron count, and time and temperature effects were investigated. The major problem associated with the nuclear method was concerned with access-tube installation. Results showed that the nuclear method of soil-moisture determination was fast and efficient. The accuracy of the method was found to be satisfactory when compared to gravimetric results, and recalibration

of the nuclear equipment was not found to be necessary. The nuclear method is recommended for studies concerned with the measurement of soil-moisture changes at depth. /author/

NUCLEAR RADIATION IN CONSTRUCTION CONTROL OF EARTH AND ROCKFILL DAMS
Bernell, L; Sherman, KA
Soil Mech & Fdn Eng Conf Proc /Mexico/ pp 285-289, 2 FIG, 4 REF
SUBFILE: TRRL; IRRD; HRIS
Recently nucldar radiation techniques have been widely used in soil investigation to determine certain characteristic properties of soils. Principally the development in this field has been concentrated on methods for determining the moisture content in soils and the density conditions in-situ and in compacted embankments, whereas very little attention has been devoted to the possibility of applying the new technique to other fields of soil-and rock mechanics (bernell and lindbo, 1965). In connection with the design and construction of several earth and rockfill dams, the Swedish state power board has developed a nuclear radiation technique for solving many problems in construction control. Results have led to reliable and simple methods for determining settlements in earth and rockfill embankments and for controlling the effect of grouting in soil and rock. These applications of the nuclear method are briefly described. /RRL/

INSTRUMENTATION FOR MEASUREMENT OF MOISTURE: LITERATURE REVIEW AND RECOMMENDED RESEARCH
Ballard, LF
NCHRP Report N138 60 pp 2 Fig. 15 Tab. Refs.
SUBFILE: HRIS
AVAILABLE FROM: Transportation Research Board Publications Office 2101 Constitution Avenue, NW Washington D.C. 20418
The objective of this study was to evaluate the suitability of existing instrumentation and techniques and to stimulate development of modified or new procedures to measure the amount and state of water in highway components, such as embankments, subgrades, base courses, pavements, and structures. In accomplishing this objective, the researchers conducted an extensive literature review. Those techniques that appear to be immediately applicable to highway problems were evaluated using a linear decision model for comparing instrument performance characteristics with specific moisture measurement needs. A comprehensive list of performance characteristics with which to make this comparison was compiled. The description of moisture measurement instrumentation is divided into categories according to the chemical and physical processes involved in the principle of measurement. Commercial instrumentation is available in most of these categories; however, as a rule, the instruments are not designed for use in highway engineering applications. The most suitable techniques currently available for use in highway problems are the gravimetric methods and nuclear scattering methods. For nondestructive surface or near-surface measurements, the nuclear method appears to be unexcelled. Where samples can be removed for analysis, gravimetric methods are most suitable. Oven drying is most commonly used, and normally is the standard method for correlating various highway component characteristics with moisture content. For field use, chemical extraction techniques appear to be most effective. Problems occur with all of these techniques; however, their performance is such that they can be of significant value in certain

applications. Candidate methods for evaluation in unconsolidated materials in stockpiles, bins, and conveyors; compacted materials in depth or in layers and other shapes are nuclear, radiowave, microwave resistance, capacitance, hygrometric, tensiometric, thermal conductivity, and rapid chemical and thermal extraction techniques. Certain modifications may improve the over-all performance of nuclear methods, with concurrent additional costs. One of these is the additional measurement of neutron-absorbing materials by means of the neutron gamma technique. Ignition tests also may be helpful in interpreting some measurements in clay materials. Hygrometric techniques using aluminum oxide films might benefit from improved construction methods. Extreme care in fabrication and the use of thick sputtered films should add to the quality of performance of these units. Many of the measurement problems lacking sufficient instrumentation could be handled through the development of remote-sensing techniques. One particularly promising technique is that of implant telemetry. Moisture measurement principles that are compatible with this type of remote sensing should receive future research effort.

SOME DESIGN CRITERIA FOR GAMMA BACK SCATTER SOIL DENSITY GAUGES
Lin, K; Taylor, D; Pirie, E
Soil Science Vol 108, No 4, PP 300-302, 3 FIG, 3 REF
SUBFILE: HRIS

A FORMULA IS PRESENTED WHICH PROVIDES A SATISFACTORY METHOD FOR THE DESIGNER OF SOIL DENSITY GAUGES TO DECIDE ON THE BEST GEOMETRY TO MEET HIS PARTICULAR PURPOSE. THIS FORMULA GIVES THE COUNTING RATE VS. DENSITY CHARACTERISTIC OF A GAMMA-RAY BACK-SCATTER GAUGE EXHIBITING A PEAK COUNTING RATE AT SOME SPECIFIC DENSITY DECIDED BY THE DETECTOR-SOURCE DISTANCE. THE COUNTING-RATE MAXIMA OBTAINED IN ALL CASES ARE DEPENDENT ON THE ACTUAL RANGE OF GAMMA-PHOTON ENERGIES COUNTED. HOWEVER, IN THE CASE OF INTEGRAL COUNTING, WHICH IS INVARIABLY USED BECAUSE OF THE HIGHEST SENSITIVITY WHICH THIS MODE OF COUNTING ALLOWS, THE EQUATION PRESENTED HAS BEEN SHOWN TO APPLY.

EVALUATION OF NUCLEAR METHODS OF DETERMINING SURFACE IN SITU SOIL WATER CONTENT AND DENSITY
Rosser, TB; Webster, SL
Waterways Exp Sta Misc Papers, Army Ce No S-69-15, 36 PP
SUBFILE: HRIS

LABOKATORY TESTS WERE CONDUCTED TO EVALUATE THE ACCURACY AND RELIABILITY OF MEASURING SURFACE IN SITU SOIL WATER CONTENT AND DENSITY BY THE BACKSCATTER AND DIRECT TRANSMISSION NUCLEAR METHODS USING A SINGLE NUCLEAR DEVICE AND SCALER. FIVE SOIL TYPES WERE TESTED AT EIGHT DIFFERENT DENSITIES AND WATER CONTENTS TO APPROXIMATE A FULL RANGE OF POSSIBLE CONSTRUCTION MATERIALS. TO OBTAIN COMPARATIVE RESULTS, SOIL DENSITIES OF EACH SAMPLE WERE DETERMINED BY TWO ACCEPTED CONVENTIONAL METHODS (SAND-CONE AND WATER-BALLOON) FOR DETERMINING DENSITY IN THE FIELD. TEST RESULTS INDICATED THAT IN SITU DENSITIES DETERMINED BY THE DIRECT TRANSMISSION NUCLEAR METHOD USING EITHER THE FACTORY OR A WES-DEVELOPED CALIBRATION CURVE WERE AS ACCURATE AS DENSITIES OBTAINED BY THE SAND-CONE AND WATER-BALLOON METHODS. DENSITIES DETERMINED BY THE SURFACE BACKSCATTER NUCLEAR METHOD WERE NOT SO ACCURATE AS THOSE OBTAINED BY THE CONVENTIONAL METHODS. WATER CONTENTS WERE OBTAINED BY NUCLEAR MEANS AND COMPARED WITH ACTUAL WATER CONTENTS DETERMINED FROM OVENDRIED SAMPLES. USING A WES-DEVELOPED CALIBRATION CURVE,

WATER CONTENTS OBTAINED BY THE NUCLEAR METHOD WERE SUFFICIENTLY ACCURATE FOR MOST QUALITY CONTROL FIELDWORK. WATER CONTENTS OBTAINED FROM USING THE FACTORY CALIBRATION CURVE WERE NOT ACCURATE ENOUGH FOR FIELD USE. A TEST PROCEDURE FOR DETERMINING SURFACE LAYER DENSITY AND WATER CONTENT OF SOIL BY NUCLEAR METHODS IS PRESENTED. /AUTHOR/

SCINTILLATION METHODS FOR THE DETERMINATION OF DENSITY AND MOISTURE CONTENT OF SOILS AND SIMILAR GRANULAR SYSTEMS

Roy, SE; Winterkorn, HF

Highway Research Board Bulletin 159, 1957

SUBFILE: HRIS

NUCLEAR METHODS FOR MOISTURE AND DENSITY DETERMINATIONS IN SOILS HAVE REACHED A POINT OF DEVELOPMENT THAT MADES THEM VALUABLE TOOLS TO THE ENGINEER AND SCIENTIST. THE PAPER FIRST TRACES THE HISTORY OF THE AVAILABLE TECHNIQUES AND DISCUSSES THE UNDERLYING SCIENTIFIC PRINCIPLES AS WELL AS THE CARACTERISTICS OF THE VARIOUS AVAILABLE PROBES AND OF THEIR COMPONENTS. SUBSEQUENTLY, THE PRINCIPLES AND AVAILABLE METHODS OF SCINTILLATION DETECTION ARE DESCRIBED AND ARE APPLIED TO THE DESIGN OF ACTUAL MOISTURE AND DENSITY PROBES. THE PERFORMANCE OF THESE PROBES IN LABORATORY AND EXTENSIVE FIELD TESTS ARE GIVEN AND THEIR ADVANTAGES AND SHORTCOMINGS POINTED OUT. EMPHASIS IS PLACED ON MEETING THE PRACTICAL PROBLEMS ENCOUNTERED IN FIELD CONDITIONS AS THEY AFFECT THE OPERATION OF THE PROBES AND ASSOCIATED ELECTRONIC EQUIPMENT, THE PREPARATION OF HOLES THROUGH VARIOUS SOIL TYPES, THE READINGS OBTAINED BY THE INSTRUMENTS USED, AND THE CALCULATION OF RESULTS, SO AS TO GIVE THE MOST ACCURATE DETERMINATIONS OF SOIL MOISTURE AND DENSITY. /AUTHOR/

NEUTRON AND GAMMA-RAY METHODS FOR MEASURING MOISTURE CONTENT AND DENSITY TO CONTROL FIELD COMPACTION

Horonjeff, R; Javete, DF

Highway Research Board Bulletin No 122, pp 23-34, 4 FIG, 4 TAB, 13 REF

SUBFILE: HRIS

Several publications have described in detail the use of radioactive materials to determine the moisture content and density of soils in place.one application of the nuclear method would be for control of compacted fills. The purpose of this investigation is to determine whether or not such an application is practical. It is planned to conduct tests with the nuclear equipment on various soils commonly used for fills and compare the results obtained by the nuclear method with those obtained through the use of the current field tests for moisture content and density. The material presented in this paper represents a small portion of the data it is planned to collect. The results of field tests upon a sandy loam only are given. A brief description of the principles underlying the nuclear procedure is given to aid the reader in understanding the field procedures which are described in detail. The effect of placing access tubes into the soil in different ways upon the results obtained by the nuclear method are included in the report, since these results served as the starting point for the development of a field procedure to check moisture content and density in A compacted fill. Four methods of placement were tried. Driving the access tubes yielded results which were the closest to the results obtained by the ordinary method of sampling. The results of moisture and density tests at A site in millbrae, California where several thousand yards of sandy loam are being placed each day are tabulated for

comparison between the method now in use and the nuclear procedure. It was found that the results obtained by the use of calibration curves developed on the job compared more favorably with the results obtained by the ordinary method of field sampling than did the results obtained by the use of calibration curves developed in the laboratory. When using calibration curves developed in the field the deviation between the nuclear procedure and the ordinary sampling method was slightly less than one percent water content in terms of dry weight and slightly less than three lb. Per cu. Ft. Dry density. On the other hand the deviation between the two procedures was nearly 1 1/2 percent water content in terms of dry weight and over 5 lb. Per cu. Ft. Dry density when using laboratory calibration curves. A discussion of the personnel, equipment, and time required for each procedure is also included. /author/

A NUCLEAR METHOD FOR DETECTING SMALL VARIATIONS IN DENSITY WITHIN SOIL SPECIMENS

Shackel, B

Australian Road Research Vol 3, No 9, PP 12-34, 14 FIG, 1 PHOT, 10 REF

SUBFILE: TRRL; IRRD; HRIS

A METHOD TO MEASURE VARIATIONS IN DENSITY WITHIN SMALL SPECIMENS OF SOIL, BITUMINOUS CONCRETE OR CONCRETE IS OUTLINED. CHANGES IN DENSITY ARE DETERMINED BY OBSERVING THE ATTENUATION OF A BEAM OF GAMMA RADIATION TRANSMITTED THROUGH THE SPECIMEN. THE EQUIPMENT IS DESCRIBED AND STATISTICAL REQUIREMENTS AND OTHER FACTORS AFFECTING THE ACCURACY OF RADIATION MEASUREMENTS ARE DISCUSSED. SOME EXPERIMENTS DESIGNED TO COMPARE THE UNIFORMITY ACHIEVED BY DIFFERENT METHODS OF LABORATORY COMPACTION ARE REPORTED. A/RRL/

DESIGN OF GAMMA BACKSCATTER DENSITY GAUGES

IEEE Trans Nuclear Science; Taylor, D; Pirie, E

VOL. ns-1n1 Feb 1972 pp 233-8

SUBFILE: HRIS

The importance of studying case histories in courses of instruction on nuclear instrumentation is pointed out: the byproducts of such studies can often provide useful research projects. The case of the gamma backscatter density gauge is considered as a specific example. Starting from the original type of gauge, using a fixed source-detector separation in which A counting rate vs density chart is employed, the authors discuss the elimination of "soil type" effects, the anomalous behavior of hydrogen, and the new moving-source (variable source-detector distance) gauge and the advantages which it offers (e. G., no calibration is necessary). Finally, more recent work is described showing how the density gauge may be employed for measuring the moisture content of materials as well as the density. /author/

OPTIMIZATION OF DENSITY AND MOISTURE CONTENT MEASUREMENTS BY NUCLEAR METHODS

Gardner, RP; Dunn, WL; Mcdougall, FH; Lippold, WJ

Highway Research Board NCHRP Report No 125, 1971 , 86 PP, FIGS, TABS, REFS, 3 APP

SUBFILE: HRIS

The objective was to minimize the errors identified with measurement of

density and moisture content of soils using nuclear gauges. To provide a reasonable basis for optimization, all identified errors were combined to yield A single criterion, the quality factor, which can be used to evaluate the over-all performance of a nuclear density gauge. Research aimed at minimizing moisture content measurement errors involved using the Monte Carlo or random walk method to simulate gauge response, checking the results of the simulation against experimental studies, and attempting to generalize the Monte Carlo results. The study has verified that, with proper calibration, currently available nuclear equipment for measurement of density and moisture content provides satisfactory accuracy for the control of compaction of highway embankments and base courses when used within the concept of random sampling and statistically based quality assurance programs. The quality factor is of immediate benefit in evaluating existing gauges and of long range benefit as a basis for improvement of measurement equipment.

COMPACTION MEASUREMENTS BY NUCLEAR DEVICES
Holman, FL; Eiland, EN; Mccullough, WF
Alabama State Highway Department
Jun 1969 Hpr Rept No 34, 56 PP, FIGS, TABS, 5 REF, 2 APP
SUBFILE: HRIS

STUDY WAS CONDUCTED TO DEVELOP METHODS, PROCEDURES, AND CALIBRATION CURVES FOR USING NUCLEAR DEVICES TO MAKE FIELD DENSITY AND MOISTURE MEASUREMENTS. THE NUCLEAR ASPHALT DENSITY GAUGE MEASUREMENTS WERE COMPARED WITH THE SPECIFIC GRAVITIES OF CORES CUT FROM BITUMINOUS PAVEMENTS. ANALYSIS OF DATA COLLECTED INDICATED A STANDARD ERROR ESTIMATE OF 0.04. THE DATA INDICATE THAT A SUBSTANTIAL PORTION OF THE VARIATION IS NOT EXPLAINED BY THE ESTIMATING EQUATIONS. THE NUCLEAR ASPHALT DENSITY GAUGE IS NOT RECOMMENDED FOR CONSTRUCTION CONTROL OF BITUMINOUS PAVEMENT DENSITY. THE NUCLEAR SOIL DENSITY GAUGE MEASUREMENTS WERE COMPARED TO THE WET UNIT WEIGHTS MEASURED BY THE SAND CONE METHOD IN THE FIELD AND A CALIBRATED BOX MOLD IN THE LABORATORY. THE STANDARD ERRORS OF ESTIMATE WERE 4 TO 5 PCF FOR ALL ANALYSES. VERY GOOD CORRELATIONS WERE OBTAINED IN THE LIMITED LABORATORY STUDY. DATA INDICATE THAT THE NUCLEAR DENSITY GAUGE MEASUREMENTS ARE AFFECTED BY VARIATIONS IN MATERIAL COMPOSITION AND THAT A SEPARATE CALIBRATION CURVE FOR EACH SOIL IS NECESSARY. THE SURFACE NUCLEAR SOIL DENSITY GAUGE AND MEASUREMENT PROCEDURES ARE NOT RECOMMENDED FOR CONSTRUCTION COMPACTION CONTROL FOR EMBANKMENT OR SUBGRADE SOILS. IF THIS TYPE OF GAUGE IS USED, IT IS RECOMMENDED THAT THE AIR GAP PROCEDURE BE USED AND THAT SEPARATE CALIBRATION CURVES BE ESTABLISHED FOR EACH SOIL. THE NUCLEAR SOIL MOISTURE GAUGE MEASUREMENTS WERE COMPARED TO MOISTURE CONTENTS DETERMINED BY OVEN DRYING. THE STANDARD ERRORS OF ESTIMATE WERE 1.0 PCF OR LESS. DATA INDICATE THAT A SINGLE CALIBRATION CURVE FOR THE DETERMINATION OF MOISTURE CONTENT BY THE NUCLEAR GAUGE WOULD BE SATISFACTORY FOR MOST SOILS.

THE SPATIAL RESPONSE PATTERN OF GAMMA BACKSCATTER DENSITY GAUGES
Devlin, G; Taylor, D
Journal of Soil Science Sep 1970 Vol 21, pp 297-303, 5 FIG
SUBFILE: TRRL; IRRD; HRIS

This theoretical study shows that the sensitivity of the usual type of gamma backscatter gauge changes markedly for different soil volume elements according to their position with respect to the source and detector

locations. There is a maximum in the so-called detector region and a less important maximum in the source region. Calculation shows that 50 percent of the total response of the instrument originates from 14 percent by volume of the soil from a hemisphere of diameter D, D being the source-detector separation. Since the response pattern of this type of backscatter gage is far from uniform, it is necessary to consider the response patterns in planning the conditions of experiments involving these gauges to obtain the highest sensitivity. This is of particular importance in studying soils of a heterogeneous nature. /rrl(a)/

DEVELOPMENT OF NUCLEAR METHODS FOR Q.C. OF HIGHWAY EMBANKMENT CONSTRUCTION

Mainfort, RC

Michigan Dept State Highways /Res Lab Section; Bureau of Public Roads /US/

REPORT NO: 61 E-22

SUBFILE: HRIS

THE EXTENSIVE LABORATORY AND FIELD TESTING CONDUCTED IN AN EFFORT TO PROPERLY DESIGN, CALIBRATE, AND USE THE NUCLEAR METHOD FOR COMPACTION CONTROL IN MICHIGAN IS DESCRIBED. THE STUDY INCLUDES INVESTIGATION OF ALL BASIC METHODS OF USING NUCLEAR DENSITY GAGES: BACKSCATTER, DIRECT TRANSMISSION, AIR-GAP, AND DIRECT READING, AND RECORDING CHART READOUT TECHNIQUES. ALSO INCLUDED IS AN INVESTIGATION OF THE APPLICABILITY OF RANDOM SAMPLING AND STATISTICAL CONTROL OF COMPACTION. FIELD TESTING OF THE GAGE WAS PERFORMED BOTH UNDER CAREFULLY CONTROLLED CONDITIONS AND UNDER NORMAL FIELD CONDITIONS BY ASSIGNING GAGES DIRECTLY TO CONSTRUCTION PERSONNEL. THE BASIC CONCLUSIONS ARE: (1) ALTHOUGH THE BASIC PRINCIPLES OF NUCLEAR RADIATION USED IN THE GAGES ARE SOUND, AS EVIDENCED BY RESULTS OF CAREFULLY CONTROLLED LABORATORY TESTS, THE GAGE HAS NOT BEEN SATISFACTORY WHEN USED UNDER FIELD CONDITIONS. THE PRIMARY PROBLEM APPEARS TO BE THE SENSITIVITY OF THE GAGE TO THE SURFACE LAYERS UPON WHICH IT IS PLACED. THIS NOT ONLY TENDS TO GIVE FALSE DENSITY MEASUREMENTS BUT CAN NEGATE ATTEMPTS TO OBTAIN BY CONVENTIONAL DENSITY MEASURING METHODS. SURFACE EFFECTS HAVE BEEN LESS APPARENT WHEN TESTING UNIFORM SANDS. (2) WHEN SPECIAL SURFACES WERE PREPARED FOR THE GAGES THE TIME REQUIRED PERTEST APPROACHED THAT REQUIRED FOR THE CONVENTIONAL TEST, NOW THAT THE SPEEDY MOISTURE METER IS USED IN THE LATTER METHOD. WITH LITTLE OR NO TIME SAVINGS, THE HIGH INITIAL AND OPERATING COST OF THE EQUIPMENT CANNOT BE JUSTIFIED. AND (3) EVEN WHEN USING NEW EQUIPMENT, CONSIDERABLE MAINTENANCE WAS REQUIRED RESULTING IN SERIOUS CONSTRUCTION DELAYS. /AUTHOR/

AIR GAP PROCEDURE FOR THE MEASUREMENT OF SURFACE DENSITY BY GAMMA RAY BACKSCATTER TECHNIQUE

Rostron, JP; Schwartz, AE; Brown, FB

Highway Res Circular, Hwy Res Board Aug 1966 No 44, pp 1-36, 18 FIG, 4 TAB, 5 REF

SUBFILE: HRIS

There has been increasing interest in the application of nuclear moisture-density surface gages for the control of compaction in highway construction. Although the backscatter test procedure conventionally used with this nuclear density equipment is rapid and non-destructive, it has been shown that the accuracy of these gages is questionable under certain conditions. Because of calibration difficulties, it seemed appropriate to

explore some solution to the problem. The air gap or maximum count ratio method suggested by kuhn seemed to hold greatest promise in overcoming the difficulty of calibration for different materials. The air gap required to yield the maximum count was determined from a series of counts made on various samples of typical material used in construction. It was determined that an air gap of 1 5/8 inches was the best compromise to be used in the calibration measurements. Conclusions were that' /1/ air gap calibration procedures were successfully applied to a nuclear Chicago, model p22a, surface density gage, /2/ the accuracy of the nuclear gage was improved from a standard error of estimate of plus or minus 10 pcf for the standard count ratio method to plus or minus 1.9 pcf for the air gap method when calibrating on a series of density standards with widely varying chemical composition, and /3/ the standard error of estimate between gravimetric soil densities and nuclear gage measurements was reduced from plus or minus 4.2 pcf for the standard count ratio method to plus or minus 2.1 by the use of the air gap method.

ANALYSIS AND IMPROVED DESIGN OF GAMMA-RAY BACKSCATTERING DENSITY GAGES
Preiss, K
Highway Research Record, Hwy Res Board 1966 No 107, pp 1-12, 9 FIG, 17 REF
SUBFILE: HRIS
The nuclear reactions which gamma radiation may undergo in a material of medium atomic weight, such as soil, are discussed and related to the properties of backscattering density gages. Theoretical reasoning and experimental evidence are presented to show that the effect of the chemical composition of the material may be eliminated when' /a/ the detector sees material near the source, and /b/ photons of energy below 0.1 mev are not detected. The latter may be achieved with a scintillation counter and pulse selector or by placing iron filters in front of A geiger-muller tube. The geometry defined by /a/ causes the peak in the calibration curve to move to a density so high that the count rate becomes a unique measure of density, rising over the entire range of density from 0 to 160 pcf. Errors in the density reading due to the statistics of nuclear counting and surface roughness arc discussed. /author/

EFFECTS OF TYPE OF MATERIAL ON NUCLEAR DENSITY MEASUREMENTS
Kuhn, SH
Highway Research Record, Hwy Res Board 1965 No66, Pp1-14, 15FIG, 2TAB, 5REF
SUBFILE: HRIS
The paper describes laboratory and field investigations carried out to improve the practical application of the nuclear method in highway construction. Various factors have been studied, including the effects of density gradient, source energy, and particularly soil type, on density measurements. Two methods are described for the possible elimination of the effect of soil type in practical density measurements. In the first, direct transmission is used as an auxiliary test with backscatter measurements. Results are given to illustrate the advantages of this method for determining the correct calibration curve for the backscatter method and also for the evaluation of any density gradient in the soil layer. In the second method introduction of a certain air gap between the surface probe and the soil surface is used to obtain a count ratio which, when plotted

against density, gives a positive slope relationship independent of soil type for densities up to 400 pcf. This method only employs the backscatter technique and is therefore completely nondestructive. It is shown further how the air-gap method can be used for effective density measurements on soil layers. Measurements at predetermined air gaps further permit continuous records of density to be obtained by using a suitable ratemeter. /author/

A STATISTICAL STUDY OF VARIATIONS IN MATERIALS AND COMPACTED DENSITIES BY SAND-CONE AND NUCLEAR METHODS
Gnaedinger, JP
Journal of Materials VOL. 6 NO. 4 Dec 1971 pp 818-25 3 Tab 4 Fig
SUBFILE: HRIS
The results of several gradation, consistency, and density-in-place tests, by both nuclear and sand-cone methods, on two controlled areas at the Chicago o'hare airport are described. Data on the fill and base course materials placed in the areas showed wide variation, indicating the advantage of having a large number of data for control and useful statistical analyses. Neither of the two methods is found superior in assessing the quality of the embankment fill. /author/

RAPID METHODS OF TEST FOR ROAD MEATERIALS AND ROADS
International Road Federation; Lee, AR
Dec 1971 pp 379-402, REF, APP
SUBFILE: HRIS
This is one of three "in-depth studies" appended to irf's 1971 world survey of road research. It contains as an appendix an extract, entitled "rapidity in testing materials," from the report of the PIARC (permanent international association of road congresses) technical commmittee on tests for road materials, presented at the 14th congress in Prague, 1971. This "in-depth study" supplements the PIARC report both by reporting more specifically on work at the Road Research Laboratory and by surveying work in particular European countries. The presentation is topical, under the following subject headings: tests on soils (moisture control, specific gravity, liquid limit), measurement of compaction (nuclear methods, nonnuclear rapid methods), aggregates, concrete (accelerated curing, indirect tensile test, analysis of freshly mixed concrete), bituminous mixtures (grading of aggregate and binder content, density of compacted bituminous materials), and tests on the completed road (structural strength, riding quality, skid resistance).

RELATIVE COMPACTION STUDY - FINAL REPORT
California Division Highways; Obermuller, JC; Smith, T
Mar 1971 Res Rept No M&R 652073, 115 PP, 82 FIG, 17 TAB, 9 REF
SUBFILE: HRIS
An investigation is presented of the principles involved in determination of percent relative compaction when using a statistical area concept method. Some of the variables involved with the nuclear gage were also studied. The factors involved were the wet weight method, composite test maximum density, use of a statistical range of test maximum values, comparison of standard laboratory and field methods of calibrating a nuclear gage and variations due to testing at different gage depths. It is

concluded that the field use of the wet method and composite test maximum density are good. The use of a statistical range of values appears feasible for uniform materials. The correlation of standard laboratory and field methods of calibration is generally good for density but not for moisture. The difference in test values due to testing at different depths is poor. Density and moisture determinations from one one-minute gage reading are comparable to the determination made from the average of two one-minute readings. /author/

EFFECT OF PLUS 3/4 - INCH ROCK AND OTHER FIELD VARIABLES ON NUCLEAR GAGE MOISTURE AND DENSITY DETERMINATIONS

California Division Highways; Smith, T; Hirsch, AD; Kleiman, WF; Zeiler, B; Lister, B; Fitzpatrick, R

Jan 1970 Final Rept NO M & R, 642978, PP 1-11, 68 FIG, 3 TAB, 9 REF,

SUBFILE: HRIS

The objectives are: (1) to study the effect of more than 10% of plus 3/4-inch rock fragments on soil density and moisture as determined by nuclear gages; (2) to study the effect on nuclear moisture determinations when corrugated metal pipe, structural plate pipe, and portland cement concrete are in close proximity to the nuclear gage. Nuclear moisture and density measurements were taken on samples of roadway excavation and structure back fill from various locations throughout the state under a variety of field and laboratory test conditions. Increasing percentage of plus 3/4-inch rock did not affect nuclear moisture content, dry density or percent relative compaction in any systematic manner. Data obtained confirms that the sand volume method is no more reliable than the nuclear gage method when wet densities are compared with the measured wet weight unit volume of soil obtained by direct measurements. The depth of nuclear gage below the surface of surrounding soil and the proximity of a concrete structure to the gage both affect nuclear moisture determinations. Horizontal clearance around the gage is also found to affect nuclear readings, but to a lesser degree than the depth variable. /author/

MEASURING THE VARIABILITY OF COMPACTED EMBANKMENTS

Jorgenson, JL

Highway Research Record, Hwy Res Board 1969 No 290, pp 23-34, 14 FIG, 2 TAB, 4 REF, 1 APP

SUBFILE: HRIS

The methods and results are presented of measuring the variability of percent compaction and moisture content of compacted embankments in acceptable highway construction in North Dakota. Separate from the state highway department's control sampling, randomly located samples were taken on each of three typical construction projects. At each sample location, the following duplicate samples were taken: (1) in-place density using the water-balloon method, (2) in-place moisture by drying two soil samples, (3) moisture and density using a nuclear moisture-density gage in both direct transmission and backscatter positions, and (4) A sack sample for determination of maximum density. For comparison, state highway department data collected during the same construction period are also reported. The major conclusions are that (1) the variability in percent compaction is large - for example, every third sample will deviate from the average by at least 3 to 5 percent, (2) the average percent compaction was very near the required minimum, (3) the higher in-place densities and lower standard

deviations of the highway department results could have resulted from the use of representative samples or from resampling, (4) a laboratory calibration of the two nuclear density gages indicated very close agreement with the manufacturer's curves, (5) the nuclear instrument, when in the direct transmission position, is a much more reliable indicator of field density than when in a backscatter position and is slightly more reliable than the conventional water-balloon tests; and (6) the air-gap procedure was more reliable than the standard block only on that project believed to have a larger variation in chemical content of the soil. /author/

DENSITY AND MOISTURE CONTENT MEASUREMENTS BY NUCLEAR METHODS
Gardner, RP; Roberts, KF
Highway Research Board NCHRP Report No 43, 1967, 38 PP, 14 FIG, 23 TAB, 9 REF , 3 APP
SUBFILE: HRIS

Sources of error that have been identified on the gamma- ray soil density gauge are: (1) sensitivity to local density variations, especially at the soil surface, (2) sensitivity to soil composition, and (3) inaccurate calibration techniques. An attempt was made to solve these problems by developing for each gauge calibration models that enable stable and homogenous non-soil standards to be used for calibration. Calibration standards and calibration models for each gauge were found and tested. In the process of developing and testing the new nuclear gauge calibration model, the dual-gauge principal of compensating these gauges for variations in soil composition was discovered. The air- gap method of using this principal is explained and was optimized by using the calibration model developed in the current study. It is concluded that this calibration method should be used in conjunction with the air-gap method for routine field use of the existing commercial nuclear density gauges. The calibration method described should be used to calculate a single calibration curve for average soil for routine field use of the existing commercial moisture content gauges. The calibration method for each gauge is explained.

DENSITY AND MOISTURE CONTENT MEASUREMENTS BY NUCLEAR METHODS INTERIM REPORT
Ballard, LF; Gardner, RP
Highway Research Board Nchrp Report No 14, 1965, 32 PP, 15 FIG, 11 TAB, 89, REF, 1 APP
SUBFILE: HRIS

Data is provided from an evaluation of the accuracy of the nuclear gages in comparison with the currently used non- nuclear methods of determining soil density and moisture content. The research study was principally theoretical in nature and was conducted in two parts with each part respectively considering density and moisture content. Two existing commercial gages were evaluated, and a nominal experimental program employing non-soil standards of known density and composition was conducted to verify the density results. The results of the moisture content study were checked against data in the literature. Theories were formulated regarding reproducibility and the primary and secondary sources of error affecting the accuracy of density and moisture content gages. Recommendations are made for either minimizing or eliminating all classes of errors, and it is concluded that when this has been accomplished the

nuclear gages provide accuracy at least equal to that of any non-nuclear technique. Detailed mathematical models were developed to express the gage response to changes in several gage parameters. The models indicated that the two most serious sources of error in density and moisture measurements are attributable to elemental composition of the soil mass and to a lack of suitable calibration standards of either soil or synthetic materials. The approach recommended for the solution of these problems is to calibrate the gages on non-soil laboratory standards that can be made homogeneous. It is proposed that this can be accomplished by using an analytical, mathematical model for calibration that includes suitable composition and density terms.

IMPROVED NUCLEAR GAGE DEVELOPMENT--FINAL REPORT
Champion, FC; Lister, B; Hannon, JB; Forsyth, RA
California Department of Transportation Transportation Laboratory, 5900 Folsom Boulevard Sacramento California 95819 19202-632857
Dec 1978 Final Rpt. 60 p.
REPORT NO: FHWA-CA-78-35
CONTRACT NO: F-4-8; Contract
SUBFILE: HRIS; NTIS
AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161
This report describes the final phase of the design, construction and evaluation of a prototype automated vehicular carried nuclear moisture-density backscatter gage. Gage development was based upon resarch and analysis of several factors that affect gage performance. Those studies indicated that the prototype backscatter gage measurements were approximately equivalent to measurements obtained by commercial transmission gages. The implication of this research finding is the possibility of a backscatter test method as a valid, reliable, and expedient procedure for determining in-situ soil conditions. Field comparisons between the prototype gage and a commerical nuclear backscatter gage showed a 20% improvement in performance by the prototype. During Phases I and II the prototype gage was installed on a motor vehicle together with a hydraulically operated mechanism that automatically positions the gage for testing. The vehicle gage unit, or Autoprobe, can determine in-situ moisture and density values in about three minutes. Phase III activities largely involved refining of the Autoprobe and the gage positioning mechanism based upon data developed by Phases I and II. The auto probe is now ready for use by the department for investigational and quality control purposes. /FHWA/ Sponsored by the California Department of Transportation. Conducted in cooperation with the Department of Transportation, Federal Highway Administration.

PRECISION OF THE RELATIVE COMPACTION TEST USING NUCLEAR GAGES
California State Dept. of Transportation, Benson, PE; Kuhl, DJ
Dec 1976 47p
REPORT NO: 631153; FHWA/CA-76/1153
SUBFILE: NTIS
AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161
Precision statements for the relative compaction test under varying conditions are given. The precision of the in situ density determination is based on application of Test Method No. Calif. 231-F using nuclear gages

and a sampling technique called the area concept. Maximum wet density precision is based on ASTM-D1557-70. A model for nuclear gage repeatability is established and the adequacy of current calibration procedures is evaluated. The precision of ASTM-D1557-70 using California operators is reported. A number of pertinent variance components are isolated with respect to the overall relative compaction variance. Also, the variation of density determinations within a relatively uniform area is given for treated and untreated soils. Precision statements for a number of California concrete and aggregate test methods are also summarized. See also rept. dated Jun 75, PB-252 491.

IMPROVED NUCLEAR GAGE DEVELOPMENT - PHASE I AND II
Chan, EL; Champion, FC; Castanon, DR; Chang, JC; Hannon, JB
California Department of Transportation; Transportation Laboratory, 5900 Folsom Boulevard; Sacramento; California; 95819; 95814
Sep 1976 Intrm Rpt. 227 pp
REPORT NO: CA-DOTTL2857-1-76-45; 632857
SUBFILE: NTIS; HRIS
AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161
This report contains Phase I and II of an investigation covering the design and construction of a prototype nuclear-moisture-density backscatter gage. Gage development was based upon the analysis of several factors which affect gage performance. This research indicated that the prototype gage measurements are approximately equivalent to measurements obtained by a commercial transmission gage. The implication of this research finding concerns the qualification of the backscatter test method as a valid, reliable, and expedient procedure for determining in-situ soil conditions.

PROCEEDINGS OF THE NEW ZEALAND ROADING SYMPOSIUM 1971, VOLUME 2, SESSION J: EARTHWORKS AND TESTING, SESSION K: AGGREGATES RESEARCH, SESSION L: AGGREGATES PRACTICE
National Roads Board, New Zealand P.O. Box 12-041 Wellington New Zealand
1972 Proceeding pp 449-547 Figs. Tabs. Refs.
SUBFILE: TRRL; IRRD; HRIS
The following papers were presented in sessions J, K and L: Slopes in rock and soft rock materials, Bullen, RO; Quality control of compaction in earthworks and pavements by nuclear methods, Ferguson, DJ; Compaction control of cohesive fill, Pickens, GA; Moisture content in porous media due to temperature gradients, Raudkivi, AJ and Nguyen, VU; Effect of basecourse saturation on pavement stability, Martin, GR and Toan, DV; An investigation of the stability of unbound basecourse pavements, Bartley, FG; Granular base layers-what do we really know?, Bullen, RO and Major, NJ; Economics of quarry production of roading aggregates, Bartley, BA; Cement stabilised pavements - an evaluation of their load fatigue and shrinkage properties, Ralston, J. /TRRL/

NUCLEAR MEASUREMENT OF SUBGRADE MOISTURE
Vaswani, NK (Virginia Highway & Transportation Research Council)
Virginia University; School of Engineering and Applied Science; Charlottesville; Virginia
Jun 1975 Reprint 103 pp 6 Fig. 3 Tab. 100 Ref.

REPORT NO: #97
SUBFILE: HRIS

In this investigation it was proposed to establish a technique for measuring subgrade moisture under pavements with sufficient accuracy, and minimal effort, interference with traffic, and recalibrations. Both electrical resistance and nuclear methods were investigated. The following conclusions were reached: (1) the nuclear depth probe method of measuring subgrade moisture is more reliable and easier to use than is the electric resistance method, it does not require precalibration and a general calibration curve for a given probe design could be developed for Virginia; (2) the use of a split sampler for a 2 inch (50 mm) diameter access tube gives a snug fit between the outside wall of the access tube and the surrounding soil, and thus eliminates possible errors in measurement due to an air gap, and it also gives a semi- undisturbed sample of the subgrade soil which is needed for calibration; (3) the access tube could be driven in all types of soils through which the split sampler could pass, without becoming bent; (4) this investigation satisfactorily resolved the methods of sealing the access tube from the top and bottom and removing moisture from the access tube before testing; and (5) the standard error of estimate in the use of a nuclear calibration curve for moisture content could be reduced by using the dry density and soil sieve analysis data. Originally printed in the Proceedings of the Specialty Conference on In Situ Measurement of Soil Properties, ASCE, Raleigh, N.C., June 1-4, 1975.

AUTOMATIC NEUTRON DEVICE FOR MEASURING THE MOISTURE CONTENT OF SOIL
Couchat, P; Palumbo, O; Volat, JP; Legrand, B
Bulletin d'Informations Scientifiques & Techniques N172 Jul 1972 pp 71-76 1 Fig. 2 Phot. 3 Ref. French
SUBFILE: TRRL; IRRD; HRIS

Details are given of a neutron device, already on the industrial market, for measuring and recording automatically the moisture content of soils. The device can be completely programmed. Parameters used for the measurement of the moisture content (measurement taken with a neutron probe) are recorded on a mini-cassette for later use either by computer or manually. This moisture content meter is of great use in agriculture, civil engineering, industry, etc. /TRRL/

IMPROVED PERFORMANCE CRITERIA FOR USE IN NUCLEAR GAGE SPECIFICATIONS
Chan, EE; Champion, FD; Chang, JC; Hannon, JB; Forsyth, RA
California Department of Transportation; Transportation Laboratory; Sacramento; California; 95819
May 1975 Final Rpt. 82 pp
REPORT NO: CA-DOT-TL-210817521
CONTRACT NO: F-4(24); HP&R
SUBFILE: NTIS; HRIS
AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161

A laboratory study of nuclear moisture-density gage parameters is reported. Commercial gages were studied to determine the capabilities of present day gages. A research gage was fabricated with a system of precision modular instruments for radiation analysis and measurement and variable gage parameters. Gage geometry, configuration and components could be varied simultaneously or independently. The following gage parameters

were investigated: Source-detector-(Separation, Collimation, Selection, Shielding); Gamma photon energy discrimination; Gage configuration. These parameters were evaluated by gage response to changes in moisture, density, soil mineral composition, surface irregularities, temperature and influence by nearby objects. The objective was to develop the criteria necessary to write efficient 'state-of-the-art' specifications for nuclear-moisture density measurement gages for use in highway compaction control.

FIELD EVALUATION OF A DIRECT TRANSMISSION TYPE NUCLEAR MOISTURE-DENSITY GAUGE

Missouri State Highway Commission; Division of Materials and Research, State Highways Building; Jefferson City; Washington; Missouri; D.C.; 65101; 20590

Jan 1975 Final Rpt. 24p

REPORT NO: 74-2

SUBFILE: NTIS; HRIS; RRIS

AVAILABLE FROM: National Technical Information Service 5285 Port Royal Road Springfield Virginia 22161

Results obtained by a nuclear moisture-density gauge were correlated to those obtained by a balloon type volume device and oven drying. The nuclear testing modes were direct transmission for wet density and backscatter for moisture. Comparison tests were made on active construction projects in each of 10 soil types and graded aggregate bases from 10 stone formations. The test sites were located throughout the state. The test results were analyzed statistically by regression, correlation coefficient and t test (comparison of the means). It was found that the manufacturer's wet density calibration curve provided acceptable results in all of the Missouri soil types and stone formations tested but that the manufacturer's water calibration curve frequently furnished unacceptable values for moisture content. However, acceptable moisture content values were obtained with the nuclear gauge by use of a computed correction factor. This factor was found to be a constant for a particular soil type or stone formation on a project.

10 YEARS OF EXPERIENCE IN THE CONTROL OF COMPACTION BY MEANS OF NUCLEAR TECHNIQUES

Garciaer, ARNVM

Escuela de Ingenieros de Caminos

Revista de Obras Publicas N3064 Aug 1970 pp 817-832 9 Fig. 4 Phot. Spanish

SUBFILE: TRRL; IRRD; HRIS

This article reviews the gravimetric and nuclear methods and equipment used for controlling road structures. Solutions are proposed to problems encountered during the application of nuclear methods with regard to the density measurements of various types of soil, to the nature of the soil (especially clayey or gypsum soil), for moisture content measurements, and to the influence of other layers for determining layer thickness. Research is being conducted on dual gauge measurement methods and energy filters. Results of a comparative study of gravimetric and nuclear methods show that the latter are more economical as they require less labour force on the site, the tests are more rapid, and defects can be detected and corrected almost immediately. Savings can reach between 5 and 15% of the total cost of the structure. Applications to the study of material deposits for roads,

airports, earth dams, etc., to the preliminary control of subgrades, to the measurement of the quality of concrete or density of snow, to mines and geophysical prospection for petroleum, etc. are discussed. /TRRL/

BIBLIOGRAPHY ON DENSIFICATION OF SOILS BY EXPLOSIVE VIBRATIONS
ASCE Journal of the Construction Division VOL. 89 NO. C01 Mar 1963 pp 99-100 16 Ref.
SUBFILE: HRIS
A bibliography is presented which provides references to a glossary of terms and definitions, and to various aspects such as blasting to settle swamp fills, ground vibrations due to blasting and its effect on structures, the importance and use of relative density in soil mechanics, compaction of loose sands by vibroflotation, and laboratory methods of compacting granular soils. The compaction of dam foundation, tower foundation, and nuclear methods for measuring soil density are covered, as well as topics such as safety requirements, and the density and relative density determination of sands.

EXPERIENCE WITH RELATIVE DENSITY AS A CONSTRUCTION CONTROL CRITERION
Leary, DJ; Woodward, RJ (Woodward-Moorhouse and Associates, Incorporated)
American Society for Testing and Materials
ASTM Special Technical Publications N523 Jul 1973 Conf Paper pp 387-401 11 Fig. 6 Ref.
SUBFILE: TRRL; IRRD; HRIS
LIMITATIONS OF SEVERAL,SHALLOW AND DEEP,DIRECT AND INDIRECT METHODS TO OBTAIN RELATIVE DENSITIES ARE DISCUSSED,AND OPINIONS ARE GIVEN CONCERNING THE USE OF THESE METHODS FOR CONSTRUCTION CONTROL PURPOSES.EXPERIENCE FROM TWO EARTHWORK PROJECTS ARE GIVEN FOR:(1) DIRECT METHODS-CONVENTIONAL SAND CONE AND WATER BALLOON,CUTTING CYLINDER,MANUALLY EXCAVATED PIT,AND DENISON SAMPLER;AND (2) INDIRECT METHODS-NUCLEAR, STANDARD PLATE LOAD TEST,STANDARD PENETRATION TEST,AND STATIC CONE PENETRATION TEST.SOME OF THESE METHODS PROVED SATISFACTORY AS A MEANS OF OBTAINING RELATIVE DENSITIES, OTHERS DID NOT.THE WATER-BALLOON METHOD WAS FOUND MORE SUITABLE THAN THE SAND-CONE METHOD. REFERENCE CURVES WERE EFFECTIVE IN SOME CASES. USE OF 6-IN. DIAMETER CUTTING CYLINDERS TO OBTAIN FIELD DRY UNIT WEIGHTS WAS FOUND UNSATISFACTORY FOR SAND CONTAINING GRAVEL.RELATIVE DENSITIES OBTAINED FROM MEASUREMENTS OF INDIVIDUAL LAYERS FROM A MANUALLY EXCAVATED PIT WERE FOUND TO BE GREATER THAN THOSE OBTAINED FROM THE WATER-BALLOON METHOD.DRY UNIT WEIGHTS OBTAINED FROM DENISON SAMPLES GAVE REASONABLE RELATIVE DENSITY VALUES.RELATIVE DENSITIES FROM NUCLEAR METHODS ARE ONLY APPROXIMATE.USE OF THE STANDARD PLATE LOAD TEST TO OBTAIN RELATIVE DENSITIES WAS NOT SUCCESSFUL.HIGH STANDARD PENETRATION RESISTANCES RESULTING FROM RESIDUAL LATERAL STRESSES WERE OBTAINED IN SAND FILL COMPACTED IN LAYERS BY VIBRATORY COMPACTORS AND LEAD TO VERY HIGH INFERRED RELATIVE DENSITIES.STATIC CONE PENETRATION RESISTANCES GIVE QUALITATIVE MEASURES OF RELATIVE DENSITY OF COMPLETED EARTHWORK AND ARE USEFUL IN EVALUATING UNIFORMITY OF COMPACTION. /AUTHOR/ Presented at the 75th Annual Meeting, Los Angeles, June 25-30, 1972.

NUCLEAR METHODS OF MEASURING MOISTURE AND DENSITY OF SOILS
Hinueber, GL (Association of American Railroads Research Center)
AREA Bulletin VOL. 65 N586 Jul 1964 Proceeding pp 838-850 5 Fig 3 Phot
SUBFILE: HRIS; RRIS
AVAILABLE FROM: American Railway Engineering Association 59 East Van Buren Street Chicago Illinois 60605

Nuclear methods of measuring moisture and density of soils are presented, in an effort to determine probable stability and strength in terms of supporting power of subgrade soil. It is noted that the application of techniques using radioactive materials offers promise to the engineer in need of a simple device for quick, accurate measurement of moisture and the degree of compaction of subgrade soils during construction. Accomplishments of the radioactive equipment and precautions necessary when the equipment is used are cited. Advantages and disadvantages attributed to the nuclear method of surface soil moisture and density determination are enumerated. It is noted that presently equipment utilizing radioisotopes for determining soil moisture and density is being used by 25 state and county highway departments, 12 federal agencies and national associations, 4 soil testing laboratories, several universities, and organizations in 6 foreign countries.

APPENDIX II

TELEPHONE SURVEY FORM

NUCLEAR DENSITY TESTING OF GRANULAR MATERIALS

Telephone Contact with Research Agencies
and Transportation DOT's in the U.S.

State/Agency:

Contact:

Tel. No.:

Date: Time:

What is the standard method used?

Are you using the nuclear method?

Backscatter

Direct transmission

Air gap

Moisture content

Do you have any reports or correlations?

Other information:

Contacted by: Michael Mamlouk